RADIOLOGICAL EMERGENCY RESPONSE
OPERATIONS COURSE
(CATEGORY IV)
FOR RADIOLOGICAL EMERGENCY RESPONSE TEAMS

A. PURPOSE

To provide the participants with the information and training necessary to respond to off-site consequences of a radiological accident occurring at a fixed nuclear facility and an accident involving the transportation of radioactive materials.

B. OBJECTIVES

At the conclusion of this course, the participants should be able to:

1. Demonstrate and/or apply via practical, simulated exercises:

    a. The techniques of radiological safety and of protecting personnel from radiological hazards;

    b. Radiological monitoring equipment and techniques;

    c. Basic map reading skills;

    d. Radiological contamination assessment and control techniques;

    e. Radiological protective action guides (PAG's);

    f. Personnel and environmental sample collection;

    g. Techniques for environmental sample collection, field analysis, and laboratory analysis;

    h. Basic meteorology information;

    i. Radiological decontamination techniques applicable to personnel, equipment, vehicles, streets and roads, land and buildings, agriculture and food products;

    j. Technique of keeping factual logs or records concerning a radiological incident;

    k. Proper public and press relations and their legal ramifications;

    l. Special skills associated with first aid for radiologically contaminated and injured persons;

    m. Use of respiratory equipment.

2. Define and use the basic principles of radiological health physics including, but not limited to:

   a. The basic nuclear science concepts, and

   b. The biological effects of ionizing radiation.

3. List the radiation exposure guides for normal peacetime application;

4. Outline the parameters associated with the anatomy of a radiological accident;

5. Outline the purpose and limitations of the different types of radiation detection equipment;

6. Define radiation protection guides and their applications;

7. Recognize non-radiological hazards associated with radiological incidents;

8. Describe nuclear accident response systems, equipment, and procedures;

9. Outline the DOT regulations applicable to the transport of radioactive materials; and

10. Solve a series of basic health physics problems using appropriate "rule-of-thumb" formula.

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SECTION 1

ATOMIC STRUCTURE

This review presents the fundamental concepts of stable atoms, the symbols, units, and terminology commonly used in nuclear physics and radiological health and the concepts of ions, isotopes, and nuclear binding energy.

The atom is the simplest unit into which an element can be divided and still retain the properties of the original element. Atoms of all elements are made of three primary subatomic components: electrons, protons, and neutrons. These three primary components are so arranged that the atom may be thought of as consisting of two main parts, the nucleus and the electron cloud. A graphical representation of two atoms is shown in Figure 1.

THE NUCLEUS

The nucleus is the central portion of the atom and contains two of the three components: the protons and neutrons. They make up practically all of the mass of the atom. Protons and neutrons are often referred to as nucleons. Thus, we consider the nucleus to consist of various combinations of protons and neutrons. Gravitational, electrical, and nuclear forces act upon the nucleons. The nuclear force holding these combinations together is sufficiently great to overcome the electric force of repulsion that exists between the positively charged protons. There are other subatomic particles which are found in nature, or appear in nuclear disintigrations. Table 1 lists the subatomic particles as to whether they are fundamental components, generated particles, or derived particles.

The Electron Cloud

The electron cloud surrounds the nuclear portion of the atom and contains the electrons which are in motion about the nucleus. Since the atom as a whole is electrically neutral, the number of electrons in the electron cloud is equal to the number of positive charges (protons) in the nucleus.

The results of various studies of the electron arrangements in atoms indicate that electrons in an atom are grouped into shells each having a definite energy and a definite maximum number of electrons. This theory accounts for the physical and chemical properties of each element, and the emission of light and x-rays as well. It is customary to visualize electrons of the atom as moving about the nucleus in orbits much as the planets revolve in elliptical paths about the sun. Although this mental image is not entirely accurate, it provides a useful model for understanding the atom. These well-defined orbits (or shells) are often referred to as energy (quantum) levels since a definite minimum amount of energy is required to remove an electron from a particular shell. Each shell is denoted by a number in order of decreasing binding energy or, more commonly, by a letter designation from K to Q, as shown below.

1	2	3	4	5	6	7
K	L	M	N	O	P	Q

The first shell is designated as K, the second as L, the third M, and so on through the alphabet to Q, or seventh shell, which is the outermost shell ever found in any of the presently known elements.

Ions and Ionization

All atoms in their natural, lowest energy state have the same number of electrons as protons. Consequently, they carry no residual electric charge. When atoms combine to form compounds, the resulting molecule has the same total number of electrons as it does protons; and the molecule is also electrically neutral. Since the electron is the lightest part of the atom, and since each electron is not bound as tightly to the nucleus as the protons and neutrons are bound to each other, it is more mobile and can be removed from the atom or molecule without expending much energy. As soon as an electron is removed from an atom or molecule, the resulting component has an electric charge because the protons are then in excess of the electrons. The residual atom, remaining after the removal of an electron, and the electron itself are called ions. These are shown in Figure 2.

Ions may be charged positively or negatively and may exist in crystals, liquids, or in gases. Positive ions are produced by removing electrons from neutral atoms and molecules, whereas negative ions are created when electrons attach themselves to neutral atoms or molecules. Negative ions are also free electrons and electrons that have been removed from atoms and molecules. The magnitude of the electrical charge on the ion, in terms of electron units, is equal to the number of electrons removed from or added to a neutral atom or molecule. The magnitude of electrical charge on an ion may be calculated in terms of coulombs or electrostatic units by

multiplying the number of electrons exchanged (gained or lost) by the charge on each electron in coulombs or electrostatic units. This value is given in the table of atomic components.

The relative charge on an ion in terms of electron units is called the valence of the ion. Recently it has become common practice to consider a free electron as an ion. Ions are, therefore, defined as free electrons or atoms or groups of atoms carrying an electric charge. The relative charge of each ion is shown in the last column of Table 1.

Ionization is the process of producing ions. Anything which is able to bring about the removal of electrons from neutral atoms or molecules is capable of causing ionization or an ionizing event. Consequently, the ionizing event is spoken of as producing an ion pair which consists of the removed electron and the residual positive ion.

ATOMIC NOMENCLATURE

Before proceeding, it will greatly simplify the discussion of the atom to introduce a consistent set of definitions and symbols.

A general expression for representing a particular element is ${}^{A}_{Z}X$.

Chemical Symbols

In the general expression above, the X represents the chemical symbol of the element and is used for brevity and convenience. In referring to a specific element, the chemical symbol usually consists of the initial letter (capitalized) in the name of the element or the initial letter followed by an appropriate second letter. For example, carbon is

represented by C, chlorine by Cl, calcium by Ca, oxygen by O, and hydrogen by H.*

Atomic Number (Z)

The Z refers to the number of protons present in the atomic nucleus. This number is always the same as the number of positive charges and is called the atomic number of the element. Since atoms are electrically neutral, the number of electrons in the electron cloud is the same as the number of protons within the nucleus. Each element has an atomic number which is characteristic of the element and is synonymous with the chemical symbol. There are currently 105 elements, 105 symbols, and 105 atomic numbers. Consequently, an element may be designated in any one of the three ways: by name, by number, or by letter symbol.

Mass Number (A)

The A in the general expression ($^{A}_{Z}X$) represents the total number of particles (protons and neutrons) in the nucleus and is referred to as the mass number. The mass number is approximately equal to the atomic weight of an element.

Neutron Number (N)

The number of neutrons in the nucleus is called the neutron number (N) and is equal to the mass number minus the atomic number (A-Z).

*When this system was adopted (1779-1898), the Latin names for several metals were in common use. This is reflected in such symbols as Fe (from the Latin ferrum) for iron, Cu (cuprum) for copper, Au (aurom) for gold, Ag (argentum) for silver, Sn (stannum) for tin, and Sb (stibium) for antimony. Other unusual symbols include W, Hg, K, and Na for tungsten, mercury, potassium, and sodium.

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Isotopes

When the atoms of an element have the same number of protons but a different number of neutrons, they are said to be isotopes of the element. Such atoms are, in general, indistinguishable chemically. The chemical properties of the isotopes of an element are the same because the chemical properties depend on the number and arrangement of (orbital) electrons surrounding the nucleus which, in turn, is determined by the number of protons in the nucleus.

For example, there are three naturally-occurring isotopes of oxygen, namel $^{16}_{8}O$, $^{17}_{8}O$, and $^{18}_{8}O$. The isotope which has a mass number of 16 occurs most abundantly. Another example is hydrogen which has three isotopes, $^{1}_{1}H$, $^{2}_{1}H$, and $^{3}_{1}H$. This element is so significant that its three isotopes are sometimes called by distinct names. The isotope of mass number 1 is called hydrogen, that of 2 is deuterium, and that of 3 is tritium.

SIZE OF ATOMIC AND SUBATOMIC PARTICLES

Radius of the Nucleus

The radius of the nucleus of various nuclides, determined by different experimental methods, are generally in good agreement with each other. Except for the elements of lowest mass number, the size of the nucleus can be expressed by the following empirical equation:

$$r = r_0 A^{1/3}, \text{ where}$$

r = the radius of the nucleus of an isotope

r_0 = a constant of about 1.37×10^{-13}cm

A = the mass number.

Nuclear Density

Since the radius is proportional to the cube root of the mass number and the volume of a sphere (volume - $4/3\pi r^3$) is proportional to the cube of the radius, the volume of the nucleus is, consequently, directly proportional to the mass number and, hence, to its actual mass. Thus, since all atomic nuclei are composed of the same constitutents, namely, neutrons and protons, they have essentially the same density. This density can easily be determined since the protons (and neutrons) have a mass of about 1.67×10^{-24} gm. The radius (A = 1) from the equation $r = r_0 A^{1/3}$ is about 1.37×10^{-13}cm. The density is, thus, approximately 10^5tons/mm^3.

The Erg

To facilitate an understanding of the enormous energy contained in a small mass, consider the energy produced if one amu (1.66×10^{-24}gm) is converted into energy. This conversion can be expressed by Einstein's famous equation relating mass and energy.

$$E = mc^2$$

where: m = the mass in grams

c = the velocity of light

$$E = (1.66 \times 10^{-24}\text{gm})(3 \times 10^{10}\text{cm/sec})^2$$
$$= 1.494 \times 10^{-3}\text{gm-cm}^2/\text{sec}^2$$

The unit gm-cm^2/sec^2 is frequently encountered in physics and radiological health work. For brevity, it is commonly referred to as an erg, thus:

$$1.494 \times 10^{-3}\text{gm-cm}^2/\text{sec}^2 = 1.49 \times 10^{-3}\text{ ergs}$$

The Electron Volt

Another convenient unit of energy is the electron volt. An electron volt is defined as the amount of energy acquired by an electron when it is accelerated in an electric field which is produced by a potential difference of 1 volt. A potential, V, acting on a charge, e, is eV, then. Because e = 1.6×10^{-19} coulomb, it is possible to calculate as follows:

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ coulomb} \times 1 \text{ volt}$$
$$= 1.6 \times 10^{-19} \text{ joule}$$
$$1 \text{ eV} = 1.6 \times 10^{-12} \text{ ergs}$$

Since the electron volt is a very small amount of energy, it is more commonly expressed in thousands of electron volts (keV) or millions of electron volts (MeV).

1 million electron volts (MeV) = 1,000,000 electron volts

1 kilo-electron volts (keV) - 1000 electron volts

It is now possible to express the atomic mass unit in MeV. Since 1 amu = 1.49×10^{-3} ergs, and 1 MeV = 1.60×10^{-6} ergs, 1 amu = 931 MeV.

Therefore, if one amu could be completely transformed into energy, 931 MeV would result. To gain a concept of the magnitude of the electron volt, it may be pointed out that one MeV is the energy necessary to lift a milligra weight two-millionths of a centimeter.

NUCLEAR BINDING ENERGY

The atomic mass of a nuclide can be understood in terms of the masses of its constituent particles and a quantity called the nuclear binding energy

It might be thought that the mass of an atom would be equal to sum of the masses of the individual particles composing the atom. However, precise measurements of atomic masses show that the mass of an atom is always less than the sum of its constituent particles (as measured in the free state). This difference is called the mass defect and is the amount of mass which would be converted into energy and released if an atom were assembled from free neutrons, protons, and electrons. The energy released serves to hold the nucleons together, because the mass would have to be replaced in order to take the nucleus apart again. Since this is also the amount of energy required to split an atom into its component particles, it is called the binding energy of the particular atom. The relationship between binding energy and mass defect is given by Einstein's equation, $E = mc^2$.

The binding energy varies from atom to atom and is usually expressed in terms of the binding energy per nucleon in a particular atom. Consider the formation of deuterium as a simple example of the meaning of binding energy. Deuterium is made up of one proton and one neutron in the nucleus, and one electron outside. The atomic mass of deuterium is 2.01410 amu. The sum of the masses of its component particles, however, is:

mass of proton	= 1.00728
mass of neutron	= 1.00866
mass of electron	= .00055
sum	2.01649

Thus, the mass of the deuterium atom is less than the mass of its component particles by an amount of .00239 amu.

Since 1 amu is equivalent to 931 MeV, the binding energy of the deuterium atom may now be written as:

$$E = .00239 \times 931 \text{ MeV} = 2.23 \text{ MeV}$$

The binding energy of the electron is approximately 14 eV and is, therefore, negligible in comparison with 2.23 MeV. Thus, the entire binding energy is essentially that of the two nucleons in the nucleus of the deuterium atom or about 1.11 MeV each. An increase in binding energy provides the energy released from radioactive isotopes upon disintegration.

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Table 1. Atomic Components					
Unit	Symbol (Common & Alternate)	Relative Mass In Atomic Mass Units	Charge (Electrical) coulombs	esu	relative
<u>Fundamental</u>					
Proton	p, ${}^{1}_{1}H$	1.007276	1.6×10^{-19}	4.8×10^{-10}	+
Electron	e, β^{-}	0.000549	1.6×10^{-19}	4.8×10^{-10}	-
Neutron	n, ${}^{1}_{0}n$	1.008665	0	0	0
<u>Generated</u>					
Positron	e^{+}, β^{+}	0.000549	1.6×10^{-19}	4.8×10^{-10}	+
<u>Derived</u>					
Deuteron	d, ${}^{2}_{1}H$	2.013551	1.6×10^{-19}	4.8×10^{-10}	+
Alpha	α, ${}^{4}_{2}He$	4.001502	3.2×10^{-19}	9.6×10^{-10}	2+

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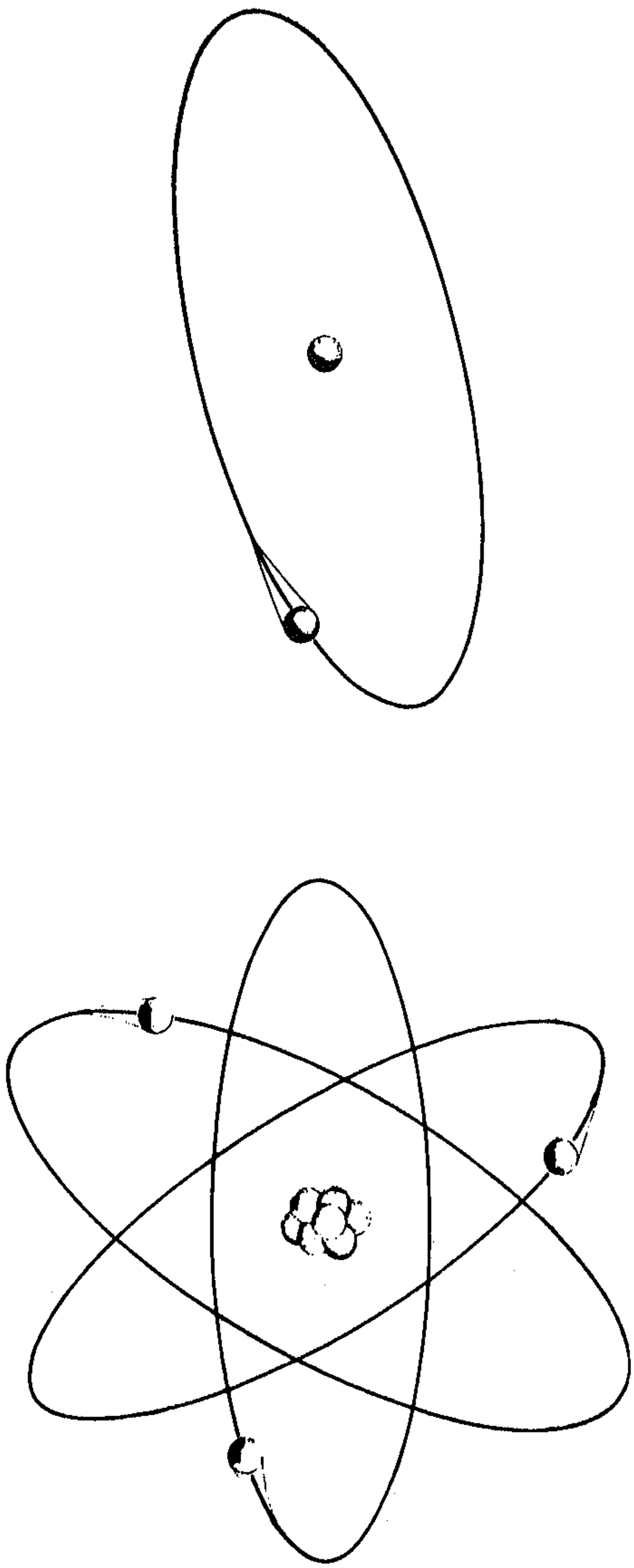

Figure 1 Hydrogen and Lithium Atoms

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SECTION 2

TRADITIONAL PHYSICS

Knowledge of the physical phenomena and scientific theory related to modern physics, nuclear reactions, and radioactivity is based on a good understanding of health physics.

Most physicists and chemists prefer to use the metric system because it is easier to change units within this system. There are seven base units of importance: they are the meter (length), kilogram (mass), second (time), ampere (electric current), kelvin or its alternate, degree Celsius (temperature), candela (luminous intensity), and mole (amount of substance).

In the metric system, prefixes are used to designate division of the base units. The following prefixes are commonly used:

tera	=	1 trillion
giga	=	1 billion
mega	=	1 million
kilo	=	1 thousand
hecto	=	one hundred
deka	=	ten
deci	=	one-tenth
centi	=	one one-hundredth
milli	=	one one-thousandth
micro	=	one one-millionth
nano	=	one one-billionth
pico	=	one one-trillionth

As an example, in a discussion of very small masses, the microgram could be used to indicate one-millionth of one gram.

Closely related to this is an exponential or power-of-ten system using multiples of 10.

This system is often known as scientific notation:

Arabic Number		Power of 10	Latin Prefix
1,000,000,000,000	=	10^{12}	tera
1,000,000,000	=	10^{9}	giga
1,000,000	=	10^{6}	mega
1,000	=	10^{3}	kilo
100	=	10^{2}	hecto
10	=	10^{1}	deka
1/10	=	10^{-1}	deci
1/100	=	10^{-2}	centi
1/1000	=	10^{-3}	milli
1/1,000,000	=	10^{-6}	micro
1/1,000,000,000	=	10^{-9}	nano
1/1,000,000,000,000	=	10^{-12}	pico

The power, or exponent, is the number written to the upper right of the 10. This exponent indicates how many times 10 is a multiplier for positive exponents or how many times 10 is a divisor for negative exponents. These exponents make multiplication and division of big numbers much simpler. For example:

$$10{,}000 \times 100{,}000 = 1{,}000{,}000{,}000$$

It is easier to write:

$$10^{4} \times 10^{5} = 10^{4+5} \text{ or } 10^{9}$$

The number 1 is written $10/10 = 10^{1-1} = 10^{0}$ or 1.

From this it can be seen that any number with an exponent of zero is equal to one.

When a negative number is subtracted, this number becomes positive. For example:

$$5 - (-4) = 5 + 4 = 9$$

From a study of the preceding examples, one can conclude that to multiply, add exponents. Conversely: to divide, subtract exponents.

$100{,}000/1{,}000 = 100$ or $10^5/10^3 = 10^{5-3} = 10^2 = 100$

$10{,}000/0.001 = 10{,}000{,}000 = 10^7$

$10{,}000/0.001 = 10^4/10^{-3} = 10^4 \times 10^{-(-3)} = 10^4 \times 10^3 = 10^7$ and

$10^{-4} = 1/10^4 = 1/10{,}000$

The chart in Figure 1 shows a scientific use of exponential notation.

To most people, work is synonymous to earning a living. To physicists, work is a force being applied through a distance: $W = Fd$. In order for work to happen, both a force and a distance must be present in the situation.

If a force of 1 dyne acts through a distance of 1 centimeter, the work done is equal to 1 erg. An erg is an extremely small amount of energy compared to the size of energies we normally witness in our surroundings. For example, it takes approximately 500 ergs to lift 1 aspirin tablet 1 centimeter.

In modern physics it has become the practice to express energies in electron units (eV), rather than ergs. The electron volt is the energy acquired by any charged particle carrying an electron charge when it moves through a potential of 1 volt. It is equal to 1.0602×10^{-12} ergs. You will normally see the terms KeV (thousand electron volts) and MeV (million electron volts)

being used because the eV is so small. Energy is defined as the capacity for doing work. An object will have energy because of its position or because of its movement. Potential energy is the energy of position. A very interesting thing about potential energy is that you cannot see it. If you release an object which has potential energy, it gains energy of motion (kinetic energy) equal to the potential energy.

Nuclear energy is a form of energy which results from rearrangements of various parts within the nucleus. Once the nuclear energy is released, and if in the proper design, it can be used for doing work.

In the study of the composition and properties of matter, the concept of electric charge is of fundamental importance. The principle of electric charge is based on certain simple experiments that anyone can perform. A typical experiment is the rubbing of a piece of hard rubber with fur. After the rubbing, the hard rubber will attract small bits of paper, hair, or other light objects. After coming in contact with the rubber, these light objects are repelled by the rubber. After contact with the rubber, they also repel one another. The explanation of these effects is that the bodies have acquired an electric charge.

Numerous experiments of the kind described lead to the conclusion that there are two kinds of charge, which are called positive and negative. Every material body normally has both kinds of charge in equal amounts, so that it appears to have no net charge. In some instances when two different substances are brought into close contact, as by rubbing them together, some negative charge moves from one body to the other, and when they are separated, each has an equal, but opposite, amount of excess charge. The excess charge on the hard rubber is the kind called negative charge;

the fur is left with an excess of positive charge. (The designations "positive" and "negative" could have been the other way around; the early experimenters just happened to agree on this "convention" for describing the electric charge.)

Two bodies with a charge of the same sign repel each other; two bodies with charges of opposite sign attract each other. The force of attraction or repulsion is proportional to the product of the amounts of charge on each body, and inversely proportional to the square of the distance between them (Coulomb's law).

Since two charges of like sign repel each other, it requires work to move a charged body toward another with a charge of the same sign. Likewise, it requires work to separate two bodies with opposite charges. This work becomes converted to a kind of potential energy called electrical energy.

Although two charges of equal amount but opposite sign may neutralize each other, no net charge has ever been created or destroyed in any experiment. Whenever a negative charge appears or disappears, an equal amount of positive charge appears or disappears at the same time.

If two bodies with equal and opposite charges are connected by a piece of metal, charge will flow through the metal until both bodies have no net charge. This flow of charge is called an electric current. Substances through which electric charge flows readily are called electrical conductors. All metals are conductors, although some are better conductors than others. Many solutions are conductors. Other substances (including gases) are ordinarily poor conductors; however, when the difference in charge between two bodies becomes great enough, an intervening nonconductor, such

as air, may "break down" and permit the flow of current. A lightning flash is a flow of current through the air between a highly charged cloud and the earth's surface.

A few substances when heated in a vacuum will give off particles of matter carrying a negative charge. This observation is part of the evidence for believing that all matter contains negatively charged particles called electrons. All electrons are alike, having the same mass and the same amount of negative charge. The electron plays an important part in the atomic theory of matter and in the theory of properties of substances. Most electric currents consist of a flow of electrons.

Magnetism is another kind of force that is observed between certain bodies of matter. Substances vary greatly in their response to magnetic force, iron being one that shows a large magnetic effect. The earth as a whole exerts a magnetic force which seems to be concentrated in regions near the two poles. A compass needle is a piece of steel that is mounted so that it can align itself in the direction of the earth's magnetic force, or magnetic field, as it is called.

Every electric current has a magnetic field around it, and the strength of the field varies with the amount of current. Magnetism is believed to be related to the motion of electrons within the atom.

If a pebble is dropped into a still body of water, a series of ripples spread out around the point where the pebble entered the water. As you observe these ripples, you see them move across the surface of the water. At any point, however, the water itself is simply moving up and down as the go by. The wave is thus seen to be a moving pattern of forces that

cause the water to rise and fall. In general, a wave is a means of energy transfer. The distance betwen two peaks or two troughs of the wave is called the wave length of the wave. The number of peaks that pass a given point each second is called the frequency of the wave.

When an electric current fluctuates, or when a charged particle vibrates, it sends out a series of waves of electric and magnetic force. These waves of force travel through empty space at the speed of light, 186,000 mi/sec (miles per second), or 3×10^8 m/sec (meters per second), and are called electromagnetic waves or electromagnetic radiation.

Electromagnetic radiation may have wavelengths of almost any size. Visible light is a particular kind of electromagnetic radiation that is able to produce the sensation of sight in the human eye. The wavelength of visible light waves range from about 4000 Å to about 8000 Å.

Electromagnetic radiations also include microwaves, radio waves, radar, gamma rays, and x-rays (see Figure 1). All electromagnetic waves have the character of transverse wave motion and undergo reflection. They show diffraction and interference effects which are regarded as typical wave properties.

The properties of radiation showing diffraction and interferences do indicate wave structure; however, the photoelectric phenomena and the Compton effect indicate that radiation consists of particles. Apparently there is some dualism for electrons. It may be shown that if a mass (m) is moving with sufficient velocity (v), it should be associated with waves of length λ given by:

$$\lambda = \frac{h}{mv}$$

where h is Planck's constant (6.626 x 10^{-34} joule - sec). Radiation of wave length λ will be equivalent to a particle of mass $h/\lambda v$ moving with speed v, where v is the velocity of light.

One of the conclusions drawn from the theory of relativity developed by Albert Einstein is that mass is a form of energy or that mass and energy are different forms of the same thing. According to the theory, the addition of energy to a body appears as an increase in its mass and the release of energy results in a decrease of mass. However, the changes in mass that occur in ordinary physical and chemical changes are much too small to detect. For example, if one foot-pound of energy is used to stretch a spring, the potential energy added to the spring is theoretically equivalent to an increase in weight of about 3 x 10^{-17} pound (0.00000000000000003 lb).

No measurable amount of mass is ever created or destroyed by a chemical reaction. In the case of a flashbulb, for example, the mass of the bulb and its contents is the same before and after the reaction which emits the flash of light. Theoretically, the mass is reduced by the equivalent of the energy that escapes through the glass. But this loss of mass is far too small to be measured.

In reactions involving changes in the nuclei of atoms, the quantities of energy involved are large enough so that measurable changes in mass do occur.

Although mass and energy are equivalent, and either one may be converted to the other, the combined total of mass and energy in the universe is believed to be fixed and unchangeable. This principle is called the law of conservation of mass and energy.

	Frequency (cycles/sec.)	Wavelength	Energy ev	ergs
	10^{23}	3×10^{-5} Å	4.1×10^{8}	6.6×10^{-4}
Cosmic-------	10^{22}	3×10^{-4} Å	4.1×10^{7}	6.6×10^{-5}
	10^{21}	3×10^{-3} Å	4.1×10^{6}	6.6×10^{-6}
Gamma--------				
	10^{20}	3×10^{-2} Å	4.1×10^{5}	6.6×10^{-7}
	10^{19}	0.3 Å	4.1×10^{4}	6.6×10^{-8}
X------------				
	10^{18}	3 Å	4.1×10^{3}	6.6×10^{-9}
	10^{17}	30 Å	4.1×10^{2}	6.6×10^{-10}
	10^{16}	300 Å	4.1×10	6.6×10^{-11}
Ultraviolet--				
	10^{15}	3×10^{3} Å	4.1	6.6×10^{-12}
	10^{14}	3×10^{4} Å	0.41	6.6×10^{-13}
Visible------				
	10^{13}	30μ	4.1×10^{-2}	6.6×10^{-14}
Infrared-----				
	10^{12}	300μ	4.1×10^{-3}	6.6×10^{-15}
	10^{11}	3 mm	4.1×10^{-4}	6.6×10^{-16}
	10^{10}	3 cm	4.1×10^{-5}	6.6×10^{-17}
	10^{9}	30 cm	4.1×10^{-6}	6.6×10^{-18}
	10^{8}	3 m	4.1×10^{-7}	6.6×10^{-19}
Radio--------				
	10^{7}	30 m	4.1×10^{-8}	6.6×10^{-20}
	10^{6}	300 m	4.1×10^{-9}	6.6×10^{-21}
	10^{5}	3 km	4.1×10^{-10}	6.6×10^{-22}
	10^{4}	30 km	4.1×10^{-11}	6.6×10^{-23}
Electric-----				
	10^{3}	300 km	4.1×10^{-12}	6.6×10^{-24}

Figure 1. Electromagnetic Radiations

SECTION 3

RADIOACTIVITY

The atom is comprised of a nucleus, consisting of neutrons and protons, and orbital electrons. The atomic number (Z) and the mass number (A) describe the quantity of these atomic components. There are 92 naturally occurring elements with atomic numbers ranging from 1 to 92. The atomic masses are approximately integral numbers that increase roughly in proportion to the atomic numbers. All elements have several isotopes, differing in mass by one or more mass units from each other. The integral nature of the increments, both in atomic number and mass number, suggests that the nucleus itself is a structure of particles (protons and neutrons) with about one atomic mass unit each. The protons carry one unit positive charge; the neutrons are neutral.

Certain structural criteria must be satisfied for a nucleus to exist in a stable state. When these criteria are not met, the nucleus will be unstable and manifest the phenomenon of radioactivity. Radioactivity refers to the processes by which a nucleus decays--or disintegrates--by one or more discrete energy steps or transitions, until a stable state is reached. The criteria which determine the stability or instability of a nucleus are briefly discussed in the following section.

NUCLEAR STABILITY

There are two sets of forces acting on the particles within the nucleus: the relatively long-range coulomb forces of repulsion between the positive charges on the protons, and the very short-range forces between both types

of particles. These latter forces are only partly understood; no attempt will be made here to discuss them. Suffice to say the combined effects of these attractive and repulsive forces are such that only certain combinations or ratios of neutrons and protons are stable.

Theoretically, if the coulomb forces were discounted, optimum stability would be achieved within a nucleus when the numbers of protons and neutrons are approximately equal. Such is the situation for the lighter elements in which the coulomb forces, relative to the short-range forces, are insignificant. These coulomb forces become increasingly signficant as the atomic number increases above 20. With large increases of these repulsive forces within nuclei, intranuclear stability conditions become altered. Consequently, with increasing atomic number, a neutron excess is required for a stable nuclide.

Thus, for elements in the Periodic Table with low atomic numbers, greater nuclear stability is found when the number of neutrons is about equal to the number of protons; stated in another manner, when the ratio of neutrons to protons (n:p ratio) is approximately equal to unity. As elements increase in Z number above 20, the n:p ratio required for stability gradually increases until Z = 83 (bismuth), where the n:p ratio required for stability exceeds 1.5:1. Finally, at the high atomic number part of the Periodic Table, above $^{209}_{83}Bi$ there are <u>no</u> completely stable nuclei. The stability conditions based on n:p ratios are <u>not</u> very critical, and "stability ranges" of n:p ratios exist for any given atomic number or mass number. For a given mass number, there may be several stable arrangements of protons and neutrons resulting in several stable isobars. For a given

atomic number, conditions may vary still more widely, so numerous stable isotopes can occur for a particular element--as many as 10 stable isotopes for some elements.

The n:p ratio is an oversimplified explanation of the intranuclear criteria leading to nuclear stability. Additional factors involving quantum-mechanical principles and binding energy considerations are needed to fully explain nuclear stability. These are beyond the scope of this presentation.

In summary, nuclear stability is governed by the particular combination and arrangement of neutrons and protons in a given nucleus. If the combination and arrangement of neutrons and protons does not fall within a "stable range," the nucleus is unstable. This is tantamount to saying the nucleus is radioactive. An unstable nucleus attempts to achieve stability by changing its configuration or ratio of neutrons and protons by means of spontaneous disintegration, or, radioactive decay.

For the purposes of this discussion, a distinction will be made between natural radioactivity and artificial radioactivity.

Natural and Artificial

Certain nuclides are unstable as they occur in nature and are therefore called "natural" radionuclides.

Others occur as a result of various man-made reactions. The vast majority of radionuclides are produced in this manner. These are called "artificial" radionuclides. The processes involved in the production of artificial radioactivity will be discussed in detail later.

History

Evidence of natural radioactivity was first reported by Henry Becquerel in 1896. Becquerel demonstrated that uranium ore would fog or darken a photographic plate shielded with opaque paper in much the same manner as x rays. He postulated that the uranium emitted very penetrating rays, similar to x rays. The phenomenon ultimately was called "radioactivity." In time, it was determined that there were many elements beyond the atomic number of lead (Z = 82) which showed similar radiating characteristics.

After a long and complicated chain of investigations, to which many outstanding physicists contributed, a better understanding of natural radioactivity was available. The understanding culminated with the experiments of Rutherford. In 1903, he clearly showed there were three kinds of radioactive emissions, namely: alpha, beta, and gamma.

TYPES OF RADIOACTIVE EMISSIONS

Alpha particles are the least penetrating of the three types of radiation. They can be absorbed or stopped by a few centimeters of air or a thin piece of paper. They have an electric charge opposite to and exactly twice that of the electron, and a mass number of 4. Thus, an alpha particle and a helium nucleus are identical in structure. With a few exceptions, only relatively heavy radioactive nuclides decay by alpha emission.

Beta particles are negatively charged particles. They have the same mass and charge as an electron and can be considered high-speed electrons. They originate in the nucleus, in contrast with ordinary electrons, which exist in the orbits around the nucleus. They travel several hundred times the

distance of alpha particles in air and require a few millimeters of aluminum to stop them. Beta activity can be expected where the n:p ratio is high. The intranuclear effect of a beta emission would be changing a neutron into a proton, decreasing the n:p ratio.

Gamma rays are a type of electromagnetic radiation and move with the speed of light. The basic difference between gamma rays and x rays is their source; gamma rays originate in the nucleus, x rays in the orbital electron structure. The basic difference between gamma rays and visible light is their frequency. The Greek symbol γ is used to designate gamma radiation.

In early investigations of radioactivity, all three of the previously mentioned radiations were commonly referred to as "rays," establishing a terminology still in use despite the fact that the term "ray" is a misnomer for particulate emissions.

Other types of emissions. There are several other types of radioactive emissions usually associated with artificial radioactivity. Because of characteristics in common with alpha, beta, and gamma rays, they are described in this section.

Positron particles are similar to beta particles except that they are positively charged. Thus, the positron can be considered a positively charged, high-speed electron which originates in the nucleus.

Orbital electron capture (K-capture) refers to the radioactive decay process whereby the nucleus captures an electron from an orbital shell of the atom. An electron from a higher energy level immediately moves in to fill the vacancy, and the excess energy is emitted as a characteristic

x-ray photon. The nucleus might conceivably capture an L-shell electron, but K-electron capture is much more probable. This mode of decay is frequently referred to as "K-capture." Orbital electron capture is generally abbreviated as "E.C."

Both positron emission and K-capture can be expected in nuclides with a low n:p ratio. The intranuclear effect of either mode of decay would be to change a proton into a neutron, thus increasing the n:p ratio.

Internal conversion occurs when a gamma photon does not escape the electron cloud surrounding the nucleus, but transfers to one of the orbital electrons enough energy to eject it from the atom. This process usually takes place in the K-shell. In principle, it is similar to the photoelectric effect.

Isomeric transition is a type of radioactive decay associated with certain pairs of nuclides that have the same mass number and the same atomic number, but different energy contents. Generally, one of the isomers of the pair is metastable and achieves ground state or a lower energy state by emitting delayed (usually greater than 10^{-9} seconds) gamma radiation. The metastable or excited state, therefore, represents one isomeric form of a particular nuclear species while the ground state represents the other.

Neutrinos are neutral particles with negligible rest mass. They account for the energy distribution among beta particles in the beta-decay process from a given radionuclide.

TRANSMUTATION

When a radioactive nuclide decays by α, β^-,β^+ or K-capture, a transmutation occurs. The decay product--or "daughter"--has become an atom of a new element with chemical properties entirely unlike the original "parent" atom.

A nucleus emitting an alpha particle disintegrates to a daughter element, reduced in atomic number by 2 and reduced in atomic mass by 4; e.g., radium decays by alpha emission to produce radon as follows:

$$^{226}_{88}Ra \qquad ^{222}_{84}Rn + ^{4}_{2}He$$

In beta emitters, the nucleus of the parent gives off a negatively charged particle, resulting in a daughter more positive by one unit of charge. The atomic number increases by one, but the mass number is unchanged; e.g., lead decays by beta emission to produce bismuth as follows:

$$^{214}_{82}Pb \qquad ^{214}_{83}Bi + ^{0}_{-1}e$$

With positron emitters, the parent nucleus gives off a positive charge. This results in a daughter <u>less</u> positive by one unit of charge. The atomic number decreases by one and the mass number remains unchanged, as in the following reaction:

$$^{57}_{28}Ni \qquad ^{57}_{27}Co + ^{0}_{1}e$$

If K-capture is the mode of decay, the transmutation resembles that of positron emission, as follows:

$$^{57}_{28}Ni + ^{0}_{-1}e \qquad ^{57}_{27}Co$$

Note that ^{57}Ni has two modes of decay. This is an example of the "branching" which is explained in the next section, Decay Phenomena.

Nuclear decay reactions resulting in a transmutation generally leave the resultant nucleus in an excited state. Nuclei, thus excited, may reach an unexcited or ground state by instantaneous emission of a gamma photon. All of the transmutation examples given would be accompanied by gamma emission. Although most nuclear decay reactions do have gamma emissions associated with them, there are numerous radionuclide species which decay by particulate emission with no gamma emission.

Decay Phenomena

Each radioactive nuclide, artificial and natural, has its own unique characteristic pattern of decay. There are two aspects associated with this "pattern"; one is the particular types and energies of the emissions involved, and the other is the rate of decay.

All nuclei of a given nuclide seeking stability by radioactive decay do so in a specific manner. As indicated, ^{226}Ra decays by an alpha emission which is accompanied by a gamma photon. This represents the only mode of decay open to ^{226}Ra. There are some radioactive nuclides which may decay with branching, whereby a choice of decay modes exists. In such case, a definite branching ratio exists. A case in point is the decay of ^{57}Ni. This isotope of nickel decays 50% by K-capture and 50% by β^+ emission. The branching ratio would be:

$$\frac{\beta^+}{EC} = 1$$

Not only do various radionuclides disintegrate in a constant manner insofar as the types of emissions are concerned, but the emissions from each nuclide exhibit a distinct energy picture. The energies associated with radiations are given in terms of "million electron volts" (MeV). Beta emissions may occur with energies to about 5 MeV; alphas to about 10 MeV; and gamma photons to about 3 MeV. The energy of the particulate radiations is manifested as kinetic energy--the higher the energy the greater the velocity of the particle. However, the velocity of photons is constant (c = speed of light) and energy differences are manifested by varying wavelengths.

The other characteristic aspect associated with decay patterns is the rate of decay. The disintegrations of radionuclides occur with a regularity characteristic for each particular species. Such disintegrations are spontaneous and random. A single radium nucleus, for instance, may disintegrate at once or wait thousands of years before emitting an alpha particle. All that can be predicted with any certainty is that half of all the ^{226}Ra nuclei present will disintegrate in 1622 years. This period is called the half-life of ^{226}Ra.

The wide range in half-life values for naturally occurring radionuclides is typified by ^{212}Po, with a half-life of 3×10^{-7} seconds, and ^{209}Bi, with a half-life of over 2×10^{18} years.

Radioactive Families

The transmutations associated with naturally occurring radionuclides frequently yield a daughter which also is radioactive. To date, about 70 different naturally occurring radionuclides have been identified, each with

its own characteristic pattern of radioactivity. Most of these yield radioactive daughters and are now known to be intimately interrelated in radioactive series or families. It has been established that most isolated radioactive species belong to one of three independent groups or families. Each family starts with a parent radionuclide, decaying or transmuting into a radioactive daughter nuclide, which would again transmute into a daughter nuclide, also radioactive, and so on until stability is attained. One family starts with uranium-238 and is called the uranium series. Another starts with thorium-232 and is called the thorium series. A third starts with uranium-235 and is called the actinium series. In each series, there is a "seesawing" in the transmutation chain between decreasing the atomic number by two with α emission and increasing it by one with β emission. Each series ends in a different stable isotope of lead. There is also a fourth series, the neptunium series, named after its longest lived member. Actually, the neptunium series has been artificially produced and does not occur in nature, but it is assumed that it did occur in nature at one time and has become extinct because of the relatively short half-lives involved. The longest lived radionuclide in the series is $^{237}_{93}Np$ with a half-life of 2.2×10^6 years. Assuming the age of the earth is 2.2×10^9 years, this would indicate that, from the time of creation, ^{237}Np has undergone 1000 half-lives decay.

The fraction of a radionuclide remaining after 1000 half-lives would be fantastically small--in the order of 10^{-300}. It is obvious, therefore, why it would be difficult to find traces of neptunium and its descendants in nature.

Singly Occurring Radionuclides

Careful measurements show that almost all materials contain traces of radioactivity. One might suspect that these traces might be due to contamination with some of the heavy radionuclides belonging to one of the radioactive series described. However, some of the lighter elements are themselves weakly radioactive. Table 1 lists five examples of naturally occurring radionuclides and their radiations.

Currently, there is no evidence that any series relationship exists among these nuclides. Therefore, they are regarded as individual, naturally occurring radionuclides with no familial relationships.

ARTIFICIAL RADIOACTIVITY

As implied in the nomenclature, natural and artificial radioactivity differ in origin. There are other distinctions between the two types which will be discussed. Nevertheless, the nuclei of artificial radionuclides are unstable in much the same manner as their natural counterparts. The intranuclear factors governing decay are also similar for both groups.

A brief account of the discovery of artificial radioactivity will be given before further discussing its similarities and dissimilarities to natural radioactivity.

Induced Transmutations

In 1919, Lord Rutherford demonstrated that it was possible to produce artificially a transmutation of elements. How naturally occurring unstable or radioactive atoms are transmuted by ejecting ionizing particles and rays has been discussed. Lord Rutherford set up and observed a nuclear

reaction in reverse, one might say, whereby high-speed charged particles (projectiles) bombarded stable atomic nuclei (target), resulting in a reaction at the nuclear level and inducing a transmutation. The first observed nuclear reaction used alpha particles from ^{214}Bi (RaC) as the charged particles. These were made to impinge upon nitrogen nuclei, acting as the target. The reaction is written as follows:

$$^{14}_{7}N + ^{4}_{2}He \qquad ^{17}_{8}O + ^{1}_{1}H$$

Since the discovery of the transmutation of nitrogen, many hundreds of artificial or induced transmutations have been found. Until 1932, most induced transmutations were performed utilizing naturally occurring alpha emitters as sources of incident particles. With the development of particle accelerators, other bombarding particles have been successfully used. No attempt will be made here to catalog the many kinds of possible transmutations, nor will any attempt be made to discuss the theory and quantitative data regarding nuclear reactions.

Induced Radioactivity

During the first 15 years of experimental work with nuclear reactions, the transmutation products (insofar as could be observed) were not radioactive. However, the reactions generally were accompanied by the emission of a charged particle and a gamma ray. These emissions are not construed as imparting the property of radioactivity to the target element, since they occur practically instantaneously.

It was determined in 1934 that induced transmutations could produce nuclei which were residually unstable in somewhat the same manner as naturally

occurring radionuclides. Madam Curie and M. Joliot reported that certain light elements (boron, magnesium, aluminum), when bombarded with alpha particles continued to emit radiation for a finite time after bombardment had stopped. The following reaction, involving aluminum bombarded with alpha particles, was the first reported instance of induced or artificial radioactivity:

$$^{27}_{13}Al + ^{4}_{2}He \qquad ^{30}_{15}P + ^{1}_{0}n$$

The resultant nucleus $^{30}_{15}P$ was observed to be radioactive, decaying by β^{+} emission with a half-life of 2.6 minutes.

The work of Curie and Joliot stimulated similar experiments throughout the world. As a result, radioactive isotopes of nearly every element in the Periodic Table were produced by bombarding a stable isotope with charged particles, neutrons, or, in certain instances, photons. Over 1,000 unstable nuclear species are listed in the Table of Isotopes.(1)

It may have been noted that carbon-14 was not included as a natural radionuclide even though it has received considerable popular attention in recent years as "naturally" occurring elemental carbon in definite, though small, proportions. The ^{14}C existing in the atmosphere is being formed continually as a result of nuclear reactions between atmospheric nitrogen and neutrons from cosmic rays. This is shown in the following reaction:

$$^{14}_{7}N + ^{1}_{0}n \qquad ^{14}_{6}C + ^{1}_{1}H$$

Naturally occurring radionuclides, in becoming stable, generally emit beta or alpha particles by a series of transmutations. Artificial radionuclides

rarely decay by alpha emission; they usually decay by β^-, β^+ emission or orbital electron capture. In contrast to natural radioactivity, induced radionuclides generally revert to stability in a single decay step.

Fission Products

Another source of radionuclides is nuclear fission. The nuclear fragments directly resulting from fission invariably have too large a proportion of neutrons to protons for stability, and consequently tend to achieve stability by negative beta emission. Each nuclear fragment initiates a radioactive series (fission decay chain) involving the successive emission of beta particles. Fission product beta emission, as with other beta emitters, generally is accompanied by gamma emission.

TABLE 1--Naturally Occurring Radionuclides

Nuclide	Half-Life	Emission Energies in MeV		
		Alpha	Beta	Gamma
$^{40}_{19}K$	1.26×10^{9}y	---	1.314	1.460
$^{87}_{37}Rb$	5.0×10^{10}y	---	0.274	---
$^{147}_{62}Sm$	1.05×10^{11}y	2.23	---	---
$^{176}_{71}Lu$	3.0×10^{10}y	---	0.43	.088 .202 .306
$^{187}_{75}Re$	4.0×10^{10}y	---	.003	.134

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SECTION 4

PHYSICAL ASPECTS OF RADIATION

Nuclear radiation possesses energy and some or all is given up to the environment or material through which the radiation travels. The radiation interacts with matter by being scattered or absorbed.

There are several reasons to look at the means by which radiation is absorbed. Some of them are:

1. Absorption in the cells of the body may cause physiological damage.
2. Shield requirements are determined in part by the degree of absorption.
3. Radiation detection is based upon the principle of absorption.

Three types of absorption to look at are alpha, beta, and gamma.

An alpha particle is made up of two protons (positively charged) and two neutrons, all strongly bound together by nuclear forces. If such a particle approaches an electron (negatively charged), it experiences a strong electrostatic attraction; whereas, if it approaches an atomic nucleus (also positively charged), it will tend to be repelled. Alpha particles have a mass about 8,000 times that of the electron. They are ejected from the nuclei of radioactive atoms with velocities on the order of 1/20 the speed of light. All of these properties--its large mass, its charge, and its high velocity tend to make the alpha particle an efficient projectile when it encounters atoms of an absorbing material. In other words, it would have a high probability of interacting or colliding with orbital electrons and also atomic nuclei.

When speaking of "collisions" between subatomic particles, it should be understood that the particles (for example, an alpha and an atomic nucleus) need approach each other only sufficiently close for forces to interact. Such an interaction may be referred to as a collision. An alpha may undergo either elastic (no transfer of energy) or inelastic (transfer of energy from the alpha radiation of the target particle) collisions.

Inelastic collisions may result in ionization and/or excitation. And since a finite amount of energy is required to ionize or excite an atom, the kinetic energy of the alpha particle is gradually dissipated by such interactions until it captures two electrons and settles down to a quiet existence as a helium atom.

Due to the high probability of interaction between an alpha particle and orbital electrons of the absorbing medium, a large number of ion pairs are formed per unit path length. And since a fraction of the kinetic energy of the alpha particle is absorbed on formation of each ion pair, this type of radiation loses its energy over a relatively short distance. For these reasons, the range of alpha particles is much less than the range of other forms of radiation. It is, in summary, a highly ionizing, weakly penetrating radiation.

Alpha particles from a given radionuclide are all emitted with the same energy; consequently, those emitted from a given source will have approximately the same range in a material. Alpha particle range is usually

expressed in centimeters of air. The relationship between range and energy has been expressed empirically as follows:

$$R_a = 0.318\ E^{3/2}$$

Where:

R_a = range in cm of air at 1 atm and 15° C

E = energy in MeV

The range of alpha radiation in solids may be compared to their range in air. The approximate relationship between range in a solid and range in air is given below:

$$R_{solid} = \frac{3.2 \times 10^{-4} R_{air}\ \sqrt{A_{solid}}}{D_{solid}}$$

R = range

D = density

A - mass number

The number of ion pairs formed per centimeter of path in any given medium is called the specific ionization for that particular ionizing radiation.

$$\text{Specific ionization} = \frac{\text{number of ion pairs formed}}{\text{centimeters of path}}$$

About 34 electron volts of energy are required for the formation of a primary ion pair in air. Only about half to two-thirds of this is required to remove the orbital electron, the balance being lost in electronic excitation processes. Depending on the energy of the alpha particle, the number of ion pairs formed per centimeter of path in air will range from 5,000 to 80,000.

The rest mass of a beta particle is the same as that of an orbital electron and, as a consequence, very much smaller than the mass of the nuclei of the atoms making up the absorbing medium. Since beta particles and orbital electrons have like charges, they experience an electrostatic repulsion when in the vicinity of one another. But a beta particle has a charge opposite to that on the atomic nucleus; therefore, an electrostatic attraction will be experienced as the beta approaches the nucleus.

All of these factors must be realized in order to understand the interaction between the beta radiation and atoms in an absorbing medium (Figure 1). For example, considering only the mass relationship between the beta particles and orbital electrons, one might expect that the interaction between these two electrons is somewhat similar to the collisions between billiard balls.

Actually, a beta particle may lose all of its energy in a single collision. In such an interaction, the target electron can effectively become an ionizing particle.

Normally a beta particle loses its energy in a large number of ionization and excitation events in a manner analogous to the alpha particle. Due to the smaller size and charge of the electron, however, there is a lower probability of beta radiation interacting in a given medium; consequently, the range of a beta is considerably greater than an alpha of comparable energy.

Since the electronic mass is small compared with that of a nucleus, large deflections can occur in single collisions, particularly when electrons of low energies are scattered by high atomic number elements (high positive charge on the nucleus). As a result, beta usually travels a tortuous, winding path in an absorbing medium.

In addition to ionization and excitation, a beta may have an interaction with an atom which results in the production of x-rays. A high-energy beta may penetrate through the electron cloud surrounding the nucleus of the atom, and in traveling through the various quantum energy states of the orbital electrons, it experiences the strong electrostatic force of the nucleus, resulting in a change in velocity and the emission of several x-rays having a spectrum of energies. (Such x-rays are referred to as "Bremsstrahlung radiation," Figure 2). It becomes an increasingly important mechanism of energy loss as the initial energy of the beta increases, and the atomic number of the absorbing medium increases. As previously pointed out, all alpha particles from a given radionuclide are emitted with the same energy. When betas are emitted, the total kinetic energy involved in the decay of the radioactive atom is divided between the beta and neutrino. The neutrino has a zero charge and negligible mass; consequently, its contribution to the overall interaction is insignificant, but it does carry away a fraction of the total kinetic energy available; therefore, the beta may be emitted with an energy varying from practically zero up to a maximum energy (which is a characteristic of the particular radionuclide).

X- and gamma rays differ only in their origin, and an individual x-ray could not be distinguished from an individual gamma ray. Both are electromagnetic waves, or quanta, and differ from radio waves and visible light waves only in having much shorter wavelengths. The difference in name is used to indicate a difference in source--gamma rays are of nuclear origin, while x-rays are of extra-nuclear origin (i.e., they originate in the electron cloud surrounding the nucleus). Both x-rays and gamma rays have zero rest mass, no net electrical charge, and travel with the speed of light. They are basically only distortions in the electromagnetic field of space, and because of

this fact, they interact electrically with atoms to produce ionization even though they themselves possess no net electrical charge. As previously pointed out, gamma rays will be discussed as the prototype of this type of radiation. There are three mechanisms by which gamma rays lose energy by interacting with matter.

The photoelectric effect is an all-or-none energy loss. The gamma wave, or photon, imparts all of its energy to an orbital electron of some atom. The gamma photon, since it consisted only of energy in the first place, simply vanishes. The energy is imparted to the orbital electron in the form of kinetic energy of motion, and this greatly increased energy overcomes the attractive force of the nucleus for the electron and causes the electron to fly from its orbit with considerable velocity. Thus, an ion-pair results. The high-velocity electron (which is called a photoelectron) has sufficient energy to knock other electrons from the orbits of other atoms, and it goes on its way producing secondary ion-pairs until all of its energy is expended.

The Compton Effect provides a means of partial energy loss for the incoming gamma ray. Again the gamma ray appears to interact with an orbital electron of some atom, but in the case of Compton interactions, only a part of the energy is transferred to the electron, and the gamma ray "staggers on" in a weakened condition. The high velocity electron, now referred to as a Compton electron, produces secondary ionization in the same manner as does the photoelectron, and the weakened gamma ray continues on until it loses more energy in another Compton interaction or disappears completely via the photoelectric effect. The unfortunate aspect of Compton interaction is that the direction of flight of the weakened gamma ray is changed. The secondary ray is frequently referred to as a "scattered" photon, and the entire process known as "Compton

scattering." By this mechanism of interaction, the direction of photons in a beam may be randomized, so that scattered radiation may appear around corners and behind "shadow" type shields.

Pair production, the third type of interaction, is much rarer than either the photoelectric or Compton effect. In fact, pair production is impossible unless the gamma ray possesses at least 1.02 MeV of energy. (Practically speaking, it does not become important until 2 MeV of energy.) In pair production, a gamma photon simply disappears in the vicinity of a nucleus, and in its place appears a pair of electrons--one negative, one positive. The mass of these electrons has been created from the pure energy of the photon, according to the familiar Einstein equation $E = mc^2$, where "E" is energy, in ergs, "m" is mass in grams, and "c" is the velocity of light in cm/sec. If there is any excess energy in the photon above the one MeV required to create two electron masses, it is simply shared between the two electrons as kinetic energy of motion, and they fly out of the atom with great velocity. The negative electron behaves in exactly the ordinary way, producing secondary ion-pairs until it loses all of its energy of motion. The positive electron (known as a positron) also produces secondary ionization so long as it is in motion, but when it has lost its energy and slowed almost to a stop, it encounters a free (negative) electron somewhere in the material. The two are attracted by their opposite charges and, upon contact, annihilate each other, converting the mass of each into pure energy. Thus two gammas of 0.51 MeV arise at the site of the annihilation. The ultimate fate of the gammas is either photoelectric absorption or Compton scattering followed by photoelectric absorption.

Figures 3, 4, and 5 illustrate the three mechanisms of gamma interaction. At low energies, the photoelectric interactions predominate; at intermediate energies, Compton scattering is the most likely interaction; and at high energies, pair production is the most important.

In principle, it should be simple to calculate the ionization produced by radiation but average responses are necessary to give good information. The energy released in cells is called a dose although the term exposure is sometimes erroneously used. There are two types of dose, the absorbed dose and the exposure dose.

The absorbed dose is defined as the energy that is imparted to the mass of a given volume or $D = \Delta E/\Delta m$. The absorbed dose is also the energy given to matter by ionizing particles per unit of irradiated material. The unit of absorbed dose is the rad and 1 rad = 100 ergs/gm or 0.01 joules/kg.

The unit of exposure of x- or gamma radiation is a measure based upon the ability to produce ionization. The unit is the roentgen (R). One roentgen is an exposure of x- or gamma radiation such that the associated ionization per 0.001293 gm of air produces ions with 1 esu of either sign. Since 1 esu is about 3.33×10^{-10} C, 1 R = 2.58×10^{-4} C/Kg. (C = Coulomb)

Historically, the most important term associated with radiation exposure has been the roentgen. There are four basic restrictions to this unit; by definition they are:

1. The medium in which exposure is defined is air; no other medium is acceptable.

2. The radiations for which exposure is defined are photons (x-ray and gamma).

3. The effect being measured is ionization of the air.

4. All electrons liberated in the ionizing processes must be stopped in air.

The last restriction serves to impose upper limits on the maximum quantum energy which may be directly measured in terms of exposure, because the range of the electrons liberated increases as a function of the energy. A chamber which measures exposure directly must have dimensions such that the distances from the electrodes to the sites of interaction are greater than the maximum range of the secondary electrons. For example, a chamber intended to measure exposure resulting from a beam of 2 MeV photons would require overall dimensions greater than 15 meters, because the maximum range in air of 2 MeV electrons which may be liberated is on the order of 7.5 meters.

The meaning of the symbol Δ (delta) is best illustrated by considering the fact that the interaction of radiation is not continuous. Interaction locations are discrete sites which can only be described statistically. If the measuring volume is too small, a single measurement of the effect may include no interaction or, through chance, several interactions may have occurred within the volume. Therefore, an average value must be determined.

Research has shown that the effect of ionizing radiations on biological systems is not related exclusively to absorbed dose. The effects observed depend on many factors and include:

1. Type of radiation
2. Energy of the radiation
3. Distribution and/or fractionation of the radiation

4. Biological endpoint chosen

5. Time at which the endpoint is evaluated

6. Species and strain of the organism utilized

Many other factors, such as the administration of certain drugs, also influence the response to radiation. In an effort to provide a comparable numerical basis for the effects of various types of radiation for protection purposes, a quantity termed the "dose equivalent" (DE) has been defined as: the product of the absorbed dose (D) quality factor (QF) and other necessary modifying factors: DE = D (QF) (. . .).

Depending upon the effect chosen for evaluation, the result obtained when the effects of two types of radiation are compared (frequently termed in radiobiological research the "relative biological effectiveness" or RBE) may vary widely. A representative value for the RBE's is selected by a committee to be used for radiation protection purposes. This value is termed the "quality factor" (QF).

Typical quality factors given here are taken from D. J. Rees, Health Physics: Principles of Radiation Protection (London: Butterworth, 1967):

Quality Factor	Type of Radiation
1.0	x-rays; γ rays; electrons; and β rays with E_{max} greater than 0.03 MeV
1.7	β rays with E_{max} not greater than 0.03 MeV
10*	Neutrons and protons up to 10 MeV
10.	Naturally occuring α particles
20.	Heavy recoil nuclei

*30. in the case of irradiation of the eyes

A quantity is necessary to describe the rate at which a radionuclide undergoes nuclear transformations. Historically, radium was used as a standard, but the International Commission on Radiation Units and Measurements (ICRU) recommendations have established a quantity which is independent of any particular substance and depends only on measurable quantities, i.e., the number of transformations occurring and the time during which these emissions took place. The quantity involved is "activity" and is defined as follows:

> The activity (A) of a quantity of a radioactive nuclide is the quotient of ΔN by Δt where ΔN is the number of nuclear transformations which occur in this quanity in time Δt.

$$A = \frac{\Delta N}{\Delta t}$$

Activity applies only to the number of nuclear transformations taking place per unit time and is not directly related to the exposure rate, absorbed dose rate, or dose equivalent rate due to the radionuclide.

Each of the quantities discussed has a measure or "unit" assigned to it. Exposure is expressed in terms of the equation

$$X = \frac{\Delta Q}{\Delta m}$$

where Q represents electrical charge (produced by ionization) per unit mass of air. Hence, any units of charge over mass would conform with the definition. The ICRU has, however, established a special unit, the use of which is restricted to measurement of exposure only.

The unit of charge used is the "coulomb," and the unit mass is the "kilogram." Specifically,

$$1 \text{ roentgen} = 2.58 \times 10^{-4} \text{ coulombs/kilogram*}$$

Absorbed dose, defined in terms of energy deposited in a mass, would demand units of energy (joules, for example) per unit mass (kilograms). Again, a special unit has been defined which is used in referring to absorbed dose:

$$1 \text{ rad} = 1/100 \text{ joule/kilogram}$$
$$= 100 \text{ ergs/gram.}$$

The unit of dose equivalent is the "rem," which is obtained by multiplying the dose in rads by the appropriate quality factor and other modifying factors. The ICRU notes in its report that this statement ". . . does not cover a number of theoretical aspects (in particular the physical dimensions of some of the quantities) . . ." but that "it fulfills the immediate requirement for an unequivocal specification of a scale that may be used for numerical expression in radiation protection." In short, since dimensionality is ignored, rems = rads x QF. Since the QF for x- and gamma radiation is 1, the number of rems is identical to the absorbed dose in rads for these radiations.

The special unit for activity is the "curie." The commission has recommended that steps be taken to redefine the curie as:

$$1 \text{ curie} = 3.7 \times 10^{10} \text{ s}^{-1} \text{ (exactly).}$$

* The magnitude of this unit does not differ from the magnitude of the previous definition.

Originally, the curie unit applied only to radium. It was based on the disintegrations per second occurring in the quantity of radon gas in equilibrium with one gram of radium. If permitted to attain this equilibrium, one gram of radium will produce about 0.66 mm^3 of radon. In this quantity of radon, about 37 billion atoms disintegrate each second.

The International Radium Standard Commission extended the definition in 1930 to include that quantity of any radioactive decay product of radium which underwent the same number of disintegrations per second as one gram of radium. It avoided specifying the figure exactly, so for some years the exact value of the curie unit varied with each successive refinement in the measurement of the decay constant or the atomic weight of radium.

In 1950, the International Joint Commission on Standards, Units, and Constants of Radioactivity redefined the curie unit by accepting 37 billion disintegrataions per second as a curie of radioactivity regardless of its source or characteristics. At present, the unit of quantity of radioactivity, the curie, merely requires that in the given sample of any material, 3.7×10^{10} disintegrations occur each second. Smaller--and often more convenient--units are the millicurie (one-thousandth of a curie: mCi) and the microcurie (one-millionth of a curie: μCi). The picocurie (3.7×10^{-2} dis/sec or 2.22 dis/min) is often used to express the very low natural and environmental levels.

The term curie originated from the number of emanations from one gram of radium. Thus, the activity of one gram of radium is equivalent to one curie. It is important, however, to note that when applied to radionuclides other than radium, the curie unit does not make apparent what weight of the material is required. Since the curie of activity is 37 billion disintegrations per

second, the weight of the material required to produce this number of disintegrations per second will be a function of the decay rate of the atoms of the material (i.e., the disintegration constant) and of the number of atoms of the material per gram (i.e., gram atomic weight). As examples, a curie of pure ^{60}Co would weigh less than 0.9 milligram, whereas a curie of natural ^{238}U would require over two metric tons of the metal. "Curies per gram" is termed "specific activity."

The activity of any sample of radioactive material decreases or decays at a fixed rate which is a characteristic of that particular radionuclide. No known physical or chemical agents (such as temperature, pressure, dissolution, or combination) may be made to influence this rate. The rate may be characterized in at least two ways, one of which is the use of the disintegration constant (λ). The disintegration constant (λ) represents the fraction of the total number of atoms present which decays in a unit time. Thus the number of disintegrations occurring per unit time in a given sample is the product of the number of atoms present in the sample, (N), and the fraction of these disintegrating in each unit time, (λ), or:

$$-\frac{dN}{dt} = \lambda N$$

where the minus sign is used to indicate that the number of atoms is diminishing. Integration of the above equation leads to the basic law of radioactive decay:

$$N_t = N_o e^{-\lambda t}$$

Written out, this equation reads: the number of atoms (N_t) remaining after a time (t) is equal to the original number (N_0) multiplied by $e^{-\lambda t}$, where (e) is the base of the natural system of logarithms and (λ) is the disintegration constant.

The disintegration constant is not as convenient as another method of representing the rate of radioactive decay. This is half-life, or $T_{1/2}$, of the radionuclide. It is the length of time required for one half of the original number of nuclei to disintegrate. The relationship of the half-life to the disintegration constant (λ) can be shown in the following way:

$$\lambda = \frac{0.693}{T_{1/2}}$$

Therefore, one may substitute this expression for (λ) in the basic decay law, and:

$$N_t = N_0 e^{-\frac{0.693t}{T_{1/2}}}$$

If it is desired to have the equation in terms of activity instead of number of atoms, one can multiply both sides of the equation by the disintegration constant (λ) as follows:

$$\lambda N_t = N_0 e^{-\frac{0.693t}{T_{1/2}}}$$

but $\lambda N = A$

therefore $A_t = A_0 e^{-\frac{0.693t}{T_{1/2}}}$

This is the working equation for computing the amount of radionuclide which will remain from the original sample after an interval of time elapses.

Example:

Given: A_o = 10 mCi of ^{32}P

t = 120 days

$T_{1/2}$ = 14.2 days

Find A_t the quantity remaining after 120 days

$$A_t = (10)e^{-\frac{(0.693)\ (120)}{14.2}}$$

$$= 10\ e^{-5.85} = 10(0.00288)$$

$$A_t = 0.0288 \text{ mCi}$$

This is the sort of calculation which would be required before diluting a radioisotope for future use or for determining the remaining activity in a quantity of nuclide which had been stored for some time since its standardization.

There is an easy graphical method of accomplishing this same computation. (See Figure 6 and 7). It is based on the relation that each successive half-life reduces the activity present by one-half, and the effect is cumulative; i.e., two half-lives reduce to 1/2 x 1/2 or 1/4; three reduce to 1/2 x 1/2 x 1/2 or 1/8, etc. In the general case, $A_n = A_o(1/2)^n$ where (n) is the number of half-lives elapsed. The answer to the "example" problem may easily be read from the graph at the point where the line intersects the horizontal axis. This number (8.44) is the number of half-lives of ^{32}P in a 120-day period. A useful "rule of thumb" to remember is that seven half-lives will reduce activity to below one percent of its original value.

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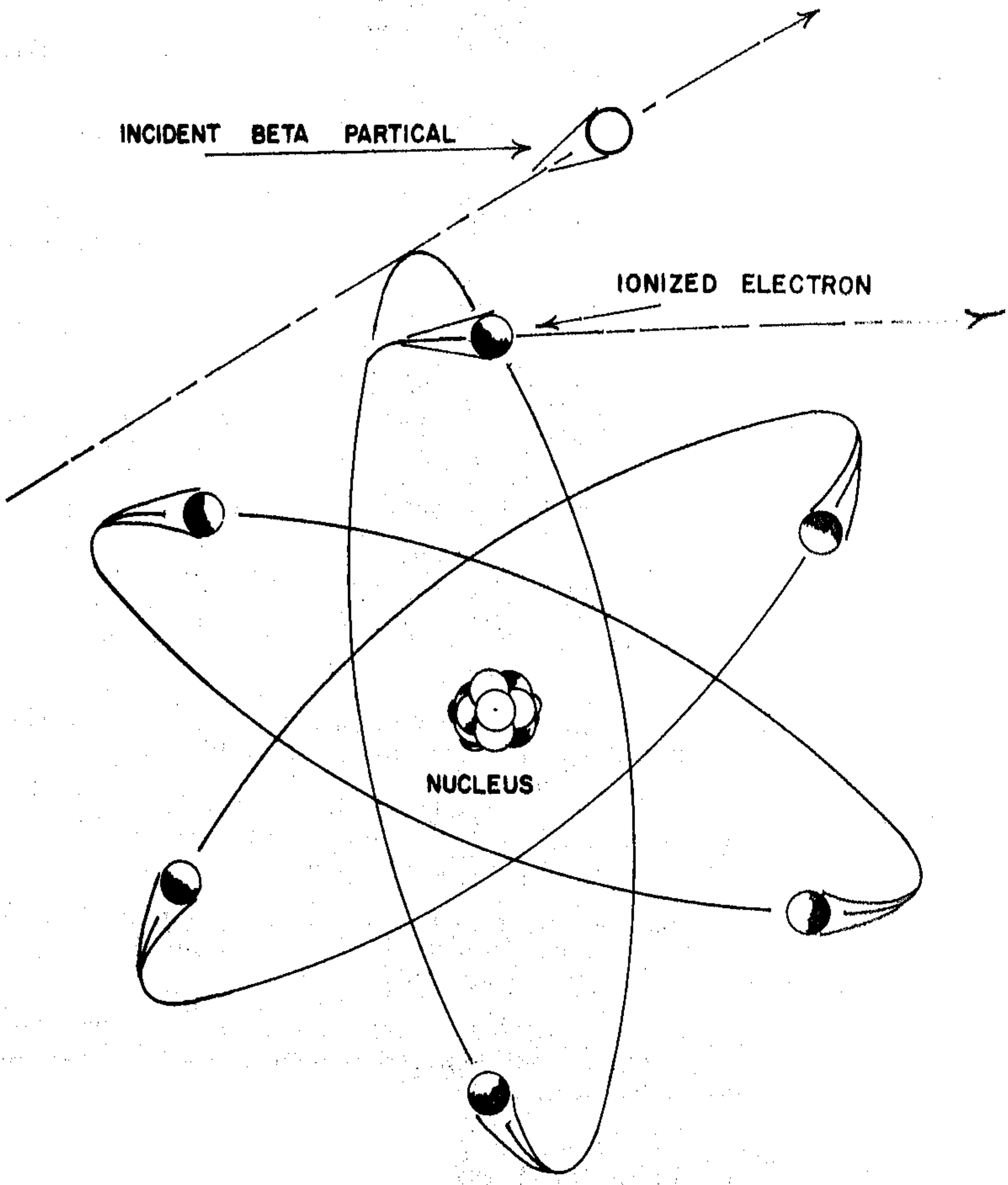

Figure 1. Beta Particle Interaction

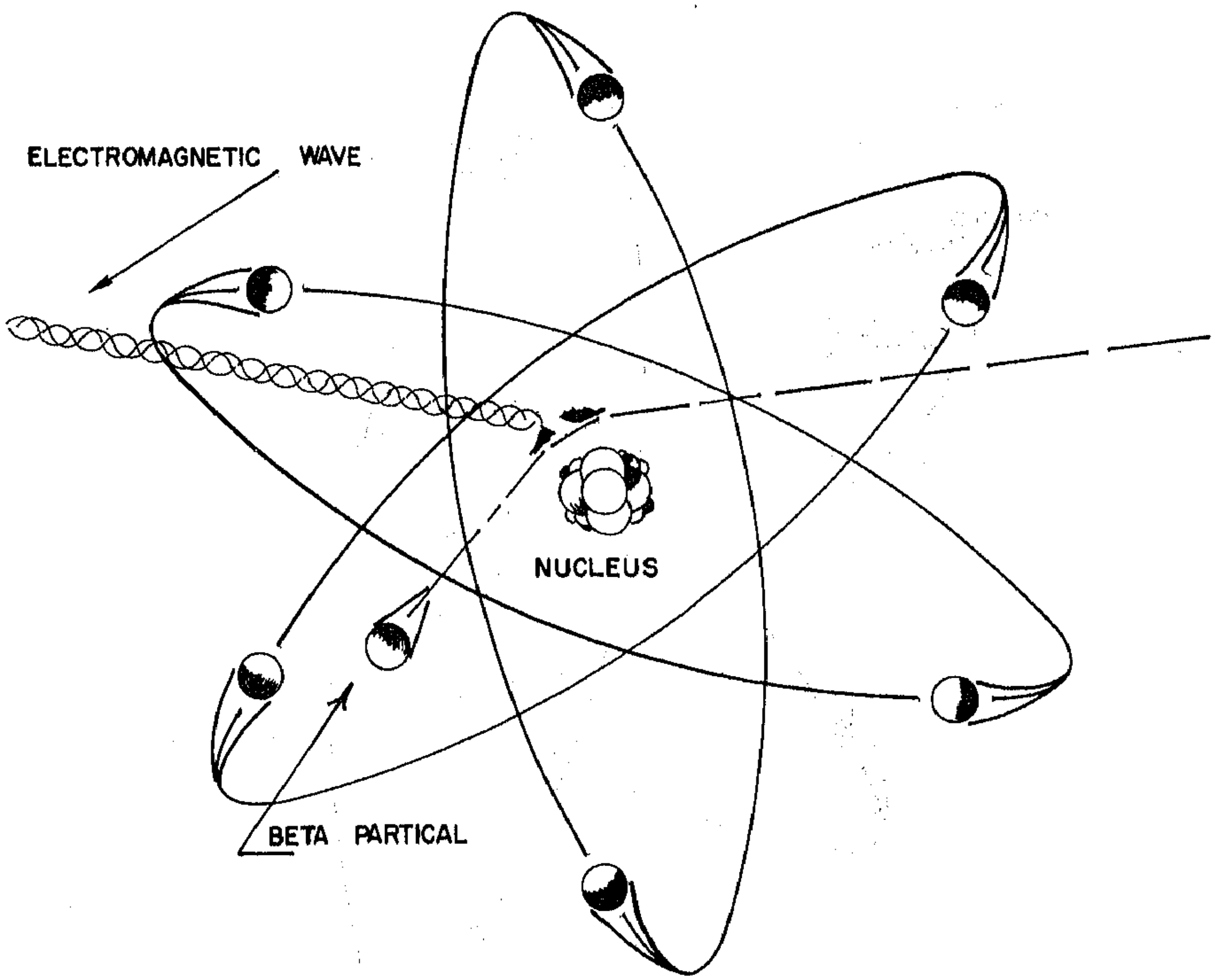

Figure 2. Bremsstrahlung

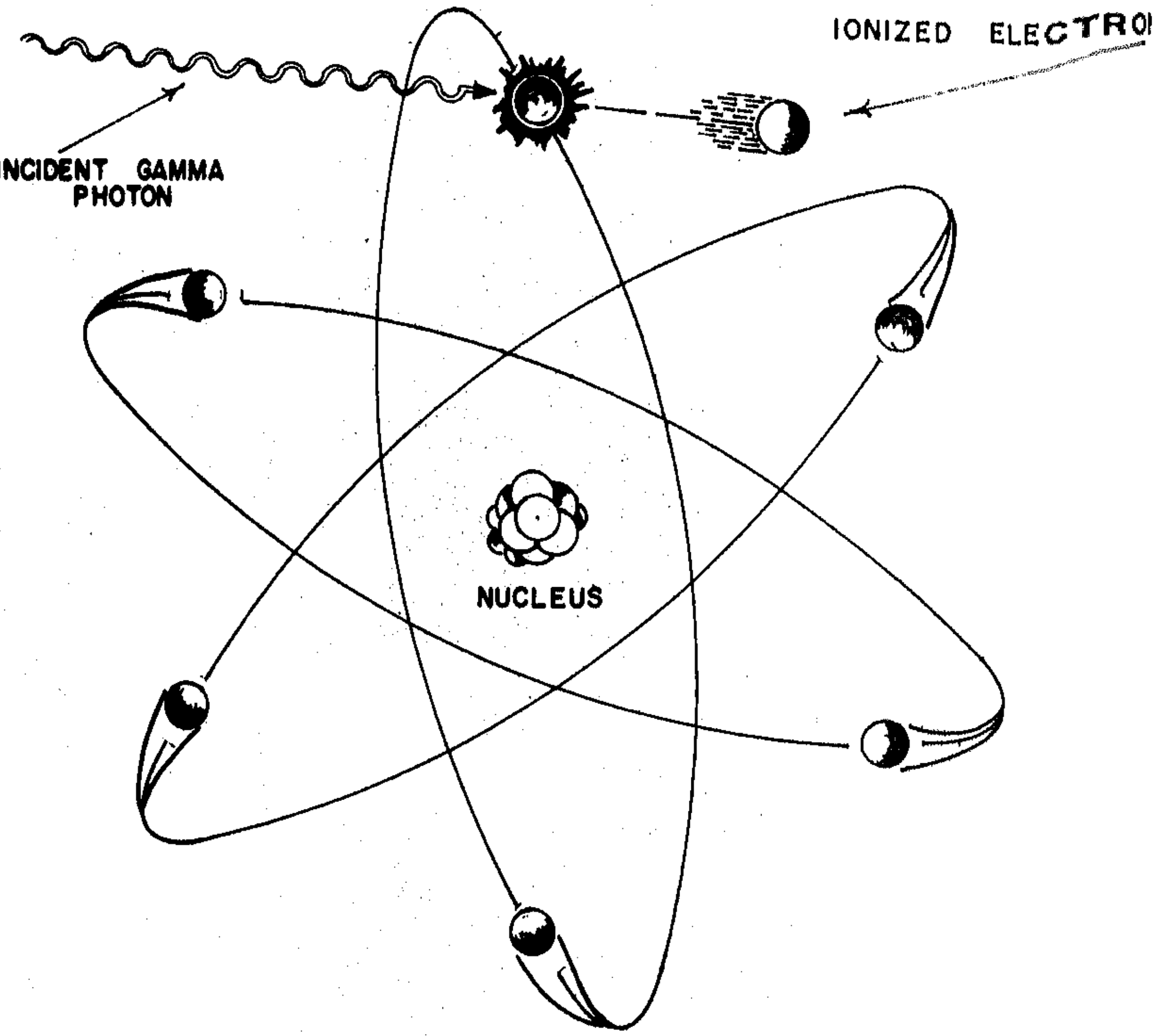

Figure 3. Photoelectric Effect

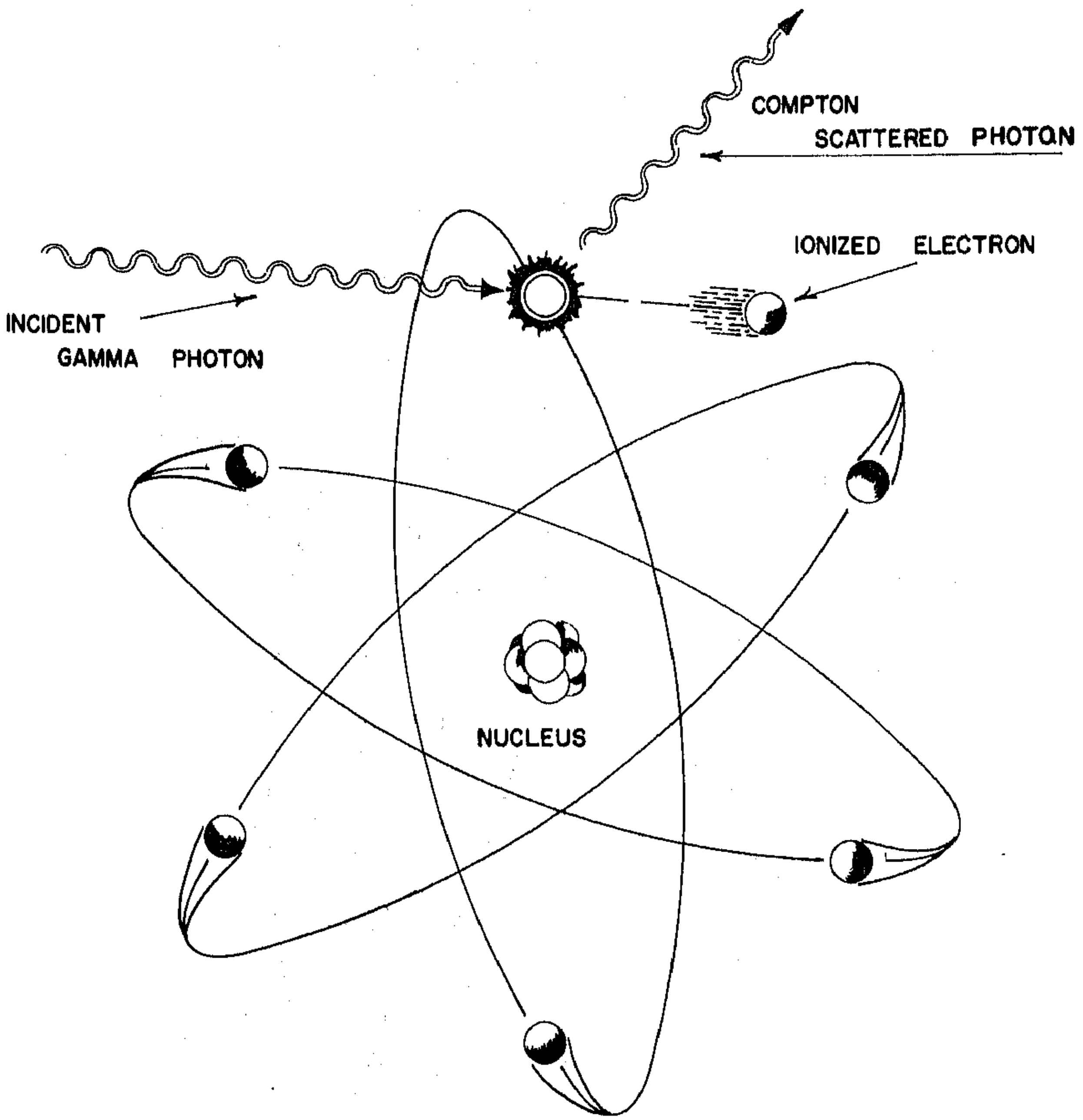

Figure 4. Compton Effect

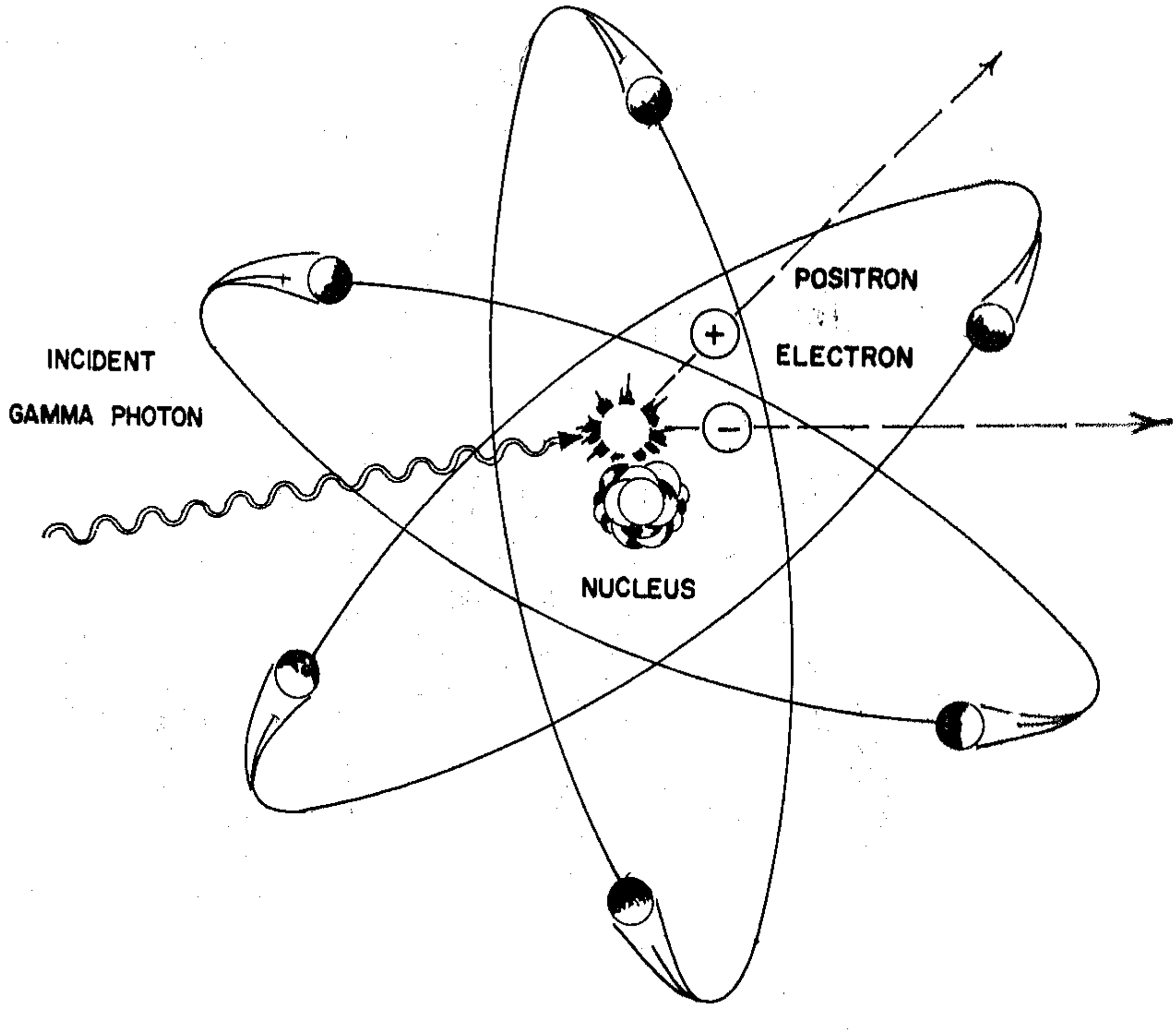

Figure 5. Pair Production

RADIOACTIVE DECAY, SEMI-LOG PLOT

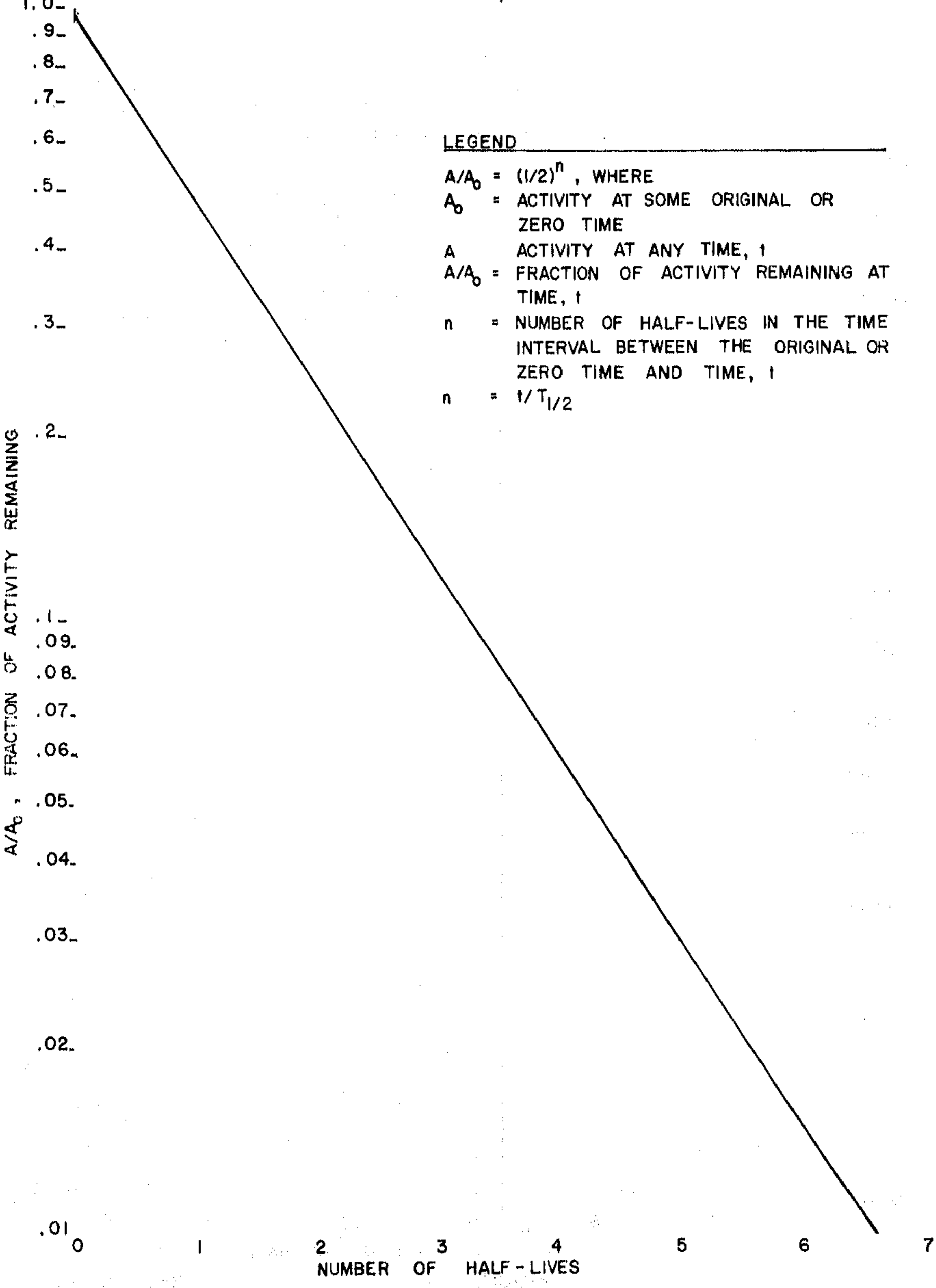

FIGURE 6

Revised: January 1978

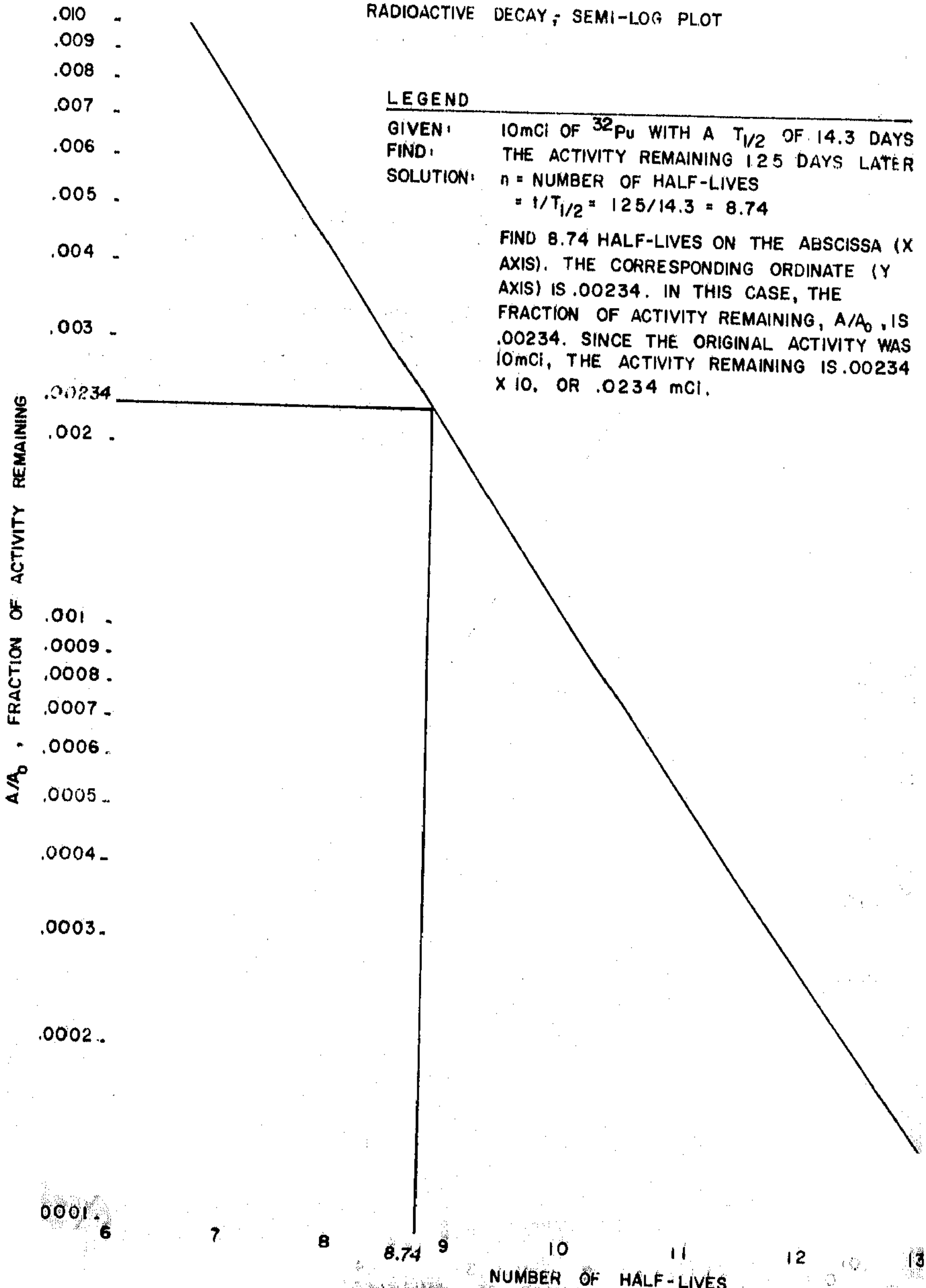
RADIOACTIVE DECAY; SEMI-LOG PLOT
LEGEND
GIVEN: 10mCi OF ^{32}Pu WITH A $T_{1/2}$ OF 14.3 DAYS
FIND: THE ACTIVITY REMAINING 125 DAYS LATER
SOLUTION: n = NUMBER OF HALF-LIVES
$= t/T_{1/2} = 125/14.3 = 8.74$
FIND 8.74 HALF-LIVES ON THE ABSCISSA (X AXIS). THE CORRESPONDING ORDINATE (Y AXIS) IS .00234. IN THIS CASE, THE FRACTION OF ACTIVITY REMAINING, A/A_0, IS .00234. SINCE THE ORIGINAL ACTIVITY WAS 10mCi, THE ACTIVITY REMAINING IS .00234 X 10, OR .0234 mCi.
A/A_0, FRACTION OF ACTIVITY REMAINING
.010
.009
.008
.007
.006
.005
.004
.003
.00234
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
6
7
8
8.74
9
10
11
12
13
NUMBER OF HALF-LIVES

FIGURE 7

SECTION 5

CRITICALITY

I AND FISSIONABLE MATERIALS

nuclei are composed of protons and neutrons, combined in such :ions that generally more neutrons than protons are required to hold ivier combinations together. Unstable nuclei show varying degrees io activity. The activity represents the adjustment of this balance :ron/proton ratio by means of a process known as beta decay. The icant feature of this process is that no nucleons are ever released e net result is either an exchange of one proton for one neutron, e versa.

ie exceptions where alpha emission occurs, this pattern holds for r combinations until isotopes of uranium are formed. The isotope ning 235 nucleons, (protons and neutrons) may be broken into two r nuclei plus excess neutrons. The process must be instituted by on or bombardment with neutrons, and a few neutrons are always ble from cosmic rays. This is called fission, and an isotope ng in this manner is called fissile. U-235 is fissile. Lighter ts may be fissioned only by high energy bombardment.

REACTIONS

eresting feature of fission is the release of the extra neutrons to hold the heavier U-235 nucleus together, but not needed in the aller fragments. Clearly, if other U-235 nuclei are nearby, the ility arises that they will be struck by these excess neutrons and e more in a cascade. In nature, U-235 is relatively rare; even when

uranium is extracted from its ores, most of the nuclei will contain 238 nucleons each, a combination which does not fission, despite the larger mass of each nucleus. The chain reaction dies out, and any sample of natural uranium is subcritical. A critical collection of U-235 nuclei could be obtained by enriching the U-235 proportion to the point where a continuing cascade of neutrons is sustained; this is then a sustained chain reaction. It is not enough to enrich the uranium, however; a large enough volume of material would also be necessary because many of the neutrons needed to sustain the action would be lost outside the sample if it were too small. By the same reasoning, the shape the sample must be nearly spherical, since for example many neutrons would be lost out the sides of a flat disc.

THERMAL NEUTRONS

There are other complications to be considered in setting up a sustained chain reaction. Idealy, the neutrons produced would be traveling slowly because fast neutrons are less likely to interact with nuclei to split them. By comparison with the natural motion of atoms due to heat, neutrons moving so slowly as to have a similar low energy are called thermal neutrons; that is, they appear to be moving by virtue of a normal temperature. It is possible to manufacture artificial fissionable materials which selectively respond to fast neutrons, providing countless possibilities for size, shape, enrichment, and composition of a critical mass of fissionable material.

Indeed, even conditions surrounding the fissionable materials affect criticality. Substances which slow fast neutrons down making more available for chain reaction, are called moderators. The addition of moderators

to a fissile material may make it go critical. These substances when placed surrounding fissile materials, may reflect neutrons back into the fissile mass. Thus, reflectors may be deliberately designed to provide a safety stop on a chain reaction, by making the mass subcritical without reflector shields in place.

In fact, it is rather difficult to assemble a critical or super critical mass for more than an instant, because the components would be thrown apart. Considerable effort is necessary to assemble the super critical mass in exploding an atomic bomb, because the components must be brought together almost instantaneously. Fast fissionable materials are used, including uranium-232 and plutonium-239, which is manufactured by neutron bombardment of U-238, the usual isotope of uranium.

REACTORS IN CRITICALITY ACCIDENTS

Because the neutrons, heat, and fission products produced in a chain reaction are very useful, critical masses are deliberately assembled with control elements to form reactors. The fissile material is the fuel, and spent elements will contain fission products. Control is usually maintained by inserting movable parts made of substances that have a high rate of interaction with neutrons. These absorbers are put in to remove enough neutrons to slow down or stop the chain reaction. The neutron and gamma radiation produced by even a small supercritical mass is intense; so much so, that even if the components of a reactor are pulled or thrown apart very quickly, lethal doses may be delivered over a large area. Therefore, two kinds of error must be considered in preparing for maximum creditable accidents; that is to say, in preparing

for the worse that can happen. The first is an inadvertant assembly of a supercritical mass. Usually, elaborate precautions are taken at every step of production, transport, and storage of fissile material to guarantee that the subcritical units are never brought together. This includes both liquid and solid volume and waste accumulations. Should these efforts fail, a supercritical mass could suddenly create intense, unsuspected radiation fields, or scatter highly toxic and radioactive materials. This is one of the few possibilities where hazards to rescue personnel may warrant delay. The victim may well be hopelessly irradiated or be contaminated to dangerous levels, or located in radiation fields too high to approach. The other possibility, with similar hazards, is loss of control of a reactor, the worse case being a melt down of the <u>core</u>, which is the fissile element. One may imagine, though it is extremely unlikely, that the intensely hot, melted fuel elements might pool into a supercritical mass that would sustain the chain reaction even as it burned its way down through the reactor containment vessel.

The fuel element for reactors are usually intense radiation sources. Along with some very large gamma sources used for radiation therapy and various other industrial applications, these elements present special shipping problems and elaborate shielding and control procedures are always required. Accidents in transportation are more likely to occur than the disasters discussed so far.

FISSION PRODUCTS

The fragments of the fissioned nucleus are usually both useful and hazardous being radioactive elements themselves. Iodine 131 is widely used in

medicine for diagnosis and therapy of thyroid disorders. Molybdenum-99 is used to make convenient sources of tracers for nuclear medicine because its short lived daughter, Technetium-99m, can be washed off periodically to make injections. Strontium-89 and Strontium-90 accumulate in the bone, and even small amounts can cause disease eventually. It is byproducts such as these that are likely to cause contamination problems in transportation accidents.

NEUTRON ACTIVATION

The major purpose of research reactors is the irradiation of various materials with neutrons. A wide variety of artificial isotopes may be produced or used as tracers, and virtually any object placed inside a reactor becomes activated; that is, radioactive isotopes are generated inside it by the high neutron flux. The significant aspect of this activation process is the use of neutron activation to evaluate personnel exposure to neutrons. Gold has a high probability of activation, and Gold 198 is readily detected due to the emission of gamma rays. Jewelry, coins, belt buckles, and the metal inserts deliberately included in some film badges may be promptly and directly measured for activation, and an estimate made of the exposure. Trace amounts of sodium in the blood, and phosphorous in the hair may be activated such that accidental exposure may be estimated from phosphorus-32 and sodium-24 contained in biological samples.

In summary, a complete range of radioactive contaminants may be produced and dispersed in a criticality or reactor accident indicating elaborate preplanning for emergency response. Furthermore, we can expect fission products in reactor fuels to be involved in transportation accidents.

SECTION 6

RADIOACTIVE MATERIALS

Many radioactive materials are commonly used in weapons, reactors, as sources for instrument calibration, in radiation studies, and in many medical applications. The vast quantities of radioactive materials that are being utilized increases the possibility of an accident or incident which could result in high-level widespread contamination.

Reactor or weapon accidents present the possibility of encountering not only the materials originally contained in the assembly, but also fission products and neutron-activated elements. When entering a contaminated area, the worst hazards must be anticipated until the actual situation is defined. In order to accomplish this, it is necessary to be familiar with the isotopes that may be encountered.

This chapter will briefly cover some of the radioisotopes that could present significant hazards and are most likely to be encountered in emergency situations. It must be realized that these are not the only isotopes that may be encountered and if they are present they may not necessarily present the greatest hazard.

Fissionable Materials

The most widely used spontaneously fissionable materials are uranium and plutonium.

1. Uranium

   Of the fourteen known isotopes of uranium, the most commonly used for fission application is ^{235}U. The isotopes ^{233}U and ^{234}U have

a high cross section for fission, will also support a chain reaction, and are used for nuclear explosive and reactor application. Under no circumstance will ^{238}U support a chain reaction; but it is widely used for other purposes.

All but three isotopes of uranium are alpha emitters and therefore present primarily an internal hazard. Because uranium is both radioactive and highly toxic (results in heavy metal poisoning similar to that of lead), it presents a unique problem to monitoring personnel. Exposure to uranium isotopes of low specific activity are often limited by the chemical toxicity rather than the radiation dose delivered to tissue. (Table 1 shows the half-life of three of the more common isotopes of uranium).

Table 1
Uranium Half-Life

Isotope	Half-Life (Years)
^{238}U	4.5×10^9
^{235}U	8×10^8
^{234}U	2×10^5

Due to its relatively low specific activity, ^{238}U presents more of a toxic hazard while ^{235}U is primarily a radiation hazard. However, protection for both of the hazards is essentially the same. Uranium, plutonium and several other metals are pyrophoric: i.e., they will ignite spontaneously. Therefore, the finely divided dust of these isotopes can burn spontaneously when exposed to air. This increases the hazard due to liberated radioactive smoke, fumes, and vapors.

Biological damage from uranium occurs mainly in the kidenys, bones, and lungs. Such is cumulative and many "small" exposures can result in serious and irrepairable biological injury.

Uranium alpha and beta emissions are more easily detected than its other radiations and are detectable with portable alpha or beta survey instruments. The contribution of uranium alpha emissions to internal dose must be approximated using laboratory bioassay techniques.

2. Plutonium

Plutonium presents the greatest radiological hazard of any of the spontaneously fissionable materials likely to be encountered. It is utilized in weapons and reactors, and its increasing use makes it highly possible that it may be present in an accident situation.

Of the 16 plutonium isotopes, ^{239}Pu, with a half-life of 2.43×10^4 years and ^{240}Pu, with a half-life of 6.6×10^3 years, are of primary interest. Since ^{239}Pu has a very high cross section for fission, it is widely used in reactors and weapons. ^{240}Pu is produced in reactors as a by-product of ^{239}Pu. Also, ^{238}Pu may be encountered in some instances and is dangerous because of its shorter half-life (89.6 years) and subsequently higher specific activity.

Plutonium ingestion can cause heavy metal poisoning. However, the amount of plutonium deposited in the body that would result in severe toxic symptons would probably be in the neighborhood of the radiation exposure $LD_{50/30}$ (Lethal dose for 50% of an exposed population group within 30 days). Once in the body, plutonium deposits in the bone

requiring about 200 years for half of the material to be eliminated. When plutonium is involved in a fire or detonation, it has a tendency to become finely divided. This can result in wide spread contamination which is difficult to detect and even more difficult to decontaminate. It should also be noted that finely divided plutonium is more pyrophoric than uranium.

Criticality must always be considered whenever working with plutonium. A 16.8 kilogram (approximately 37 lbs.) bare sphere of plutonium can constitute a critical mass. Such a sphere would have a diameter of only 12.7 centimeters (approximately 5 inches).

If a sphere of plutonium were immersed in water, only 5.6 kilograms (approximately 12 lbs.) would be needed for it to become critical. From this it is easily seen that chunks of plutonium resulting from an accident should be handled carefully. In no instance should they be stacked together.

3. Thorium

Thorium is a heavy metal physically similar to uranium, and is fissionable only with fast neutrons. Thorium is not spontaneously fissionable. In the nuclear industry, thorium has two basic uses; first as a reactor fuel (still in the developmental stages) and second in breeder reactors for the production of ^{233}U.

The most commonly occurring thorium isotope is ^{232}Th. This emits a 3.99 MeV alpha particle and a weak gamma. It has a half-life of 1.39×10^{10} years and has a slightly lower specific activity than uranium.

Two of the decay products of thorium are radon-222 and thoron-220. Actually thoron is an isotope of radon. Both isotopes are noble gases and both are alpha emitters with half lives of 3.8 days and 52 seconds respectively. These gases are found in varied concentrations in the open atmosphere where they present no effective hazard. However, in a closed atmosphere which contains a thorium source, concentrations could become hazardous. Thorium presents essentially the same safety problems as uranium. Neglecting the decay products, our main concern would be for possible heavy metal poisoning and secondly, the alpha emissions from material deposited within the body.

4. Iodine

As a cause of popular public concern, iodine is almost as well known as strontium. Like strontium, various isotopes of iodine are formed during fission reactions. Most of the 20 radioactive isotopes of iodine have very short half-lives. The one exception is ^{129}I, which has a half-life of 1.6×10^7 years. However, ^{129}I is of rather uncommon occurrence, and has a very low specific activity.

The isotope most likely to be encountered is ^{131}I with a half-life of 8.05 days. Small amounts of elemental iodine are essential to proper body functions, and it is concentrated in the thyroid gland. Iodine and its salts are readily absorbed in the mucous membranes, and once in the body nearly all of the radioactive iodine tends to collect in the thyroid gland. Due to the high specific activity of radioiodine, a relatively large dose is delivered in a short time. The allowable dose to the thyroid is 5 rem per quarter, 15 rem per year.

5. Cesium

Cesium-137, a beta-gamma emitting isotope, is also formed during fission reactions. Its half-life is 30 years. Many of the cesium compounds are highly soluble in water and body fluids. For this reason, the total body is usually considered to be the critical organ. Of the organs of the body, the liver, spleen, and muscle will usually absorb the greater percentages of cesium.

6. Tritium

Tritium is one of the three isotopes of hydrogen. It is highly active having a half-life of 12.26 years. It is usually found as a product of the fission process and may be present in dangerous quantities. Tritium emits a weak beta with an average energy of 5.7 keV. Due to its weak beta emissions, tritium is not usually considered an external hazard. However, it is easily absorbed through clothing and the skin. In a tritiated atmosphere, about 1/2 the exposure would come from inhalation and 1/2 by absorption through the skin. Once it gets into the body it is very dangerous.

Being an isotope of hydrogen, tritium reacts chemically with oxygen in an almost identical fashion as normal hydrogen. This raises several unique radiological problems. Elemental tritium in the atmosphere is less hazardous then T_2O vapor because most of the ^3H atoms inhaled are immediately exhaled. On the other hand, pure tritium is seldom found. As soon as tritium is exposed to oxygen, auto-oxidation takes place to form H_2O. Physiologically, tritium water or water vapor behaves the same as ordinary water vapors and is rapidly absorbed by the lungs and the skin.

7. Strontium

Strontium is an element having a total of 16 isotopes, most of which are negligible hazards because of their short half-lives. ^{89}Sr and ^{90}Sr have half-lives of 51 days and 28 years respectively and due to their biological effects can create many difficulties. Biologically and chemically, strontium is very similar to calcium, and as such is a bone seeker. Once in the body, strontium has a biological half-life of 50 years. ^{89}Sr and ^{90}Sr are beta emitters, but ^{89}Sr also emits a 0.91 MeV gamma. Plants have a tendency to absorb and subsequently concentrate environmental strontium. When ruminants (such as dairy cows) eat contaminated plants, almost all of the strontium is absorbed through the gastrointestinal tract. Much of the absorbed strontium is eliminated from the body during the first few days (except in those animals having a calcium deficient environment). Strontium may be transferred to humans via milk. For this reason, children can be expected to have higher concentrations per body weight than adults. The hazard in uptake of ^{90}Sr has been experimentally demonstrated to be carcinogenic.

SECTION 7

BIOLOGICAL EFFECTS OF IONIZING RADIATION

The fact that ionizing radiation produces biological damage has been known for many years. The first case of human injury was reported in the literature just a few months following Roentgen's original paper in 1895 announcing the discovery of x-rays. As early as 1902, the first case of x-ray induced cancer was reported in the literature.

Early human evidence for harmful effects as a result of exposure to radiation in large amounts existed in the 1920's and 30's, based upon the experience of early radiologists, miners exposed to airborne radioactivity underground, persons working in the radium industry, and other special occupational groups. The long-term biological significance of smaller, chronic doses of radiation, however, was not widely appreciated until relatively recently, and most of our current knowledge of the biological effects of radiation has been accumulated since World War II.

SEQUENTIAL PATTERN OF BIOLOGICAL EFFECTS

In general, the sequence of events following radiation exposure may be classified as follows:

Latent Period

Following the initial radiation event, and often before the first detectable effect occurs, there is a time lag referred to as the latent period. There is a vast time range possible in the latent period. In

fact, the biological effects of radiation are arbitrarily divided into short-term and long-term effects on this basis. Those effects which appear within a matter of minutes, days, or weeks are called short-term effects and those which appear years, decades, and sometime generations later are called long-term effects.

Period of Demonstrable Effects on Cells and Tissues

During or immediately following the latent period, certain discrete effects can be observed.

One of the phenomena that is seen most frequently in growing tissues expose to radiation is the cessation of mitosis or cell division. This may be temporary or permanent, depending upon the radiation dosage. Other effects observed are chromosome breaks, clumping of chromatin, formation of giant cells or other abnormal mitoses, increased granularity of cytoplasm, change in staining characteristics, changes in motility or ciliary activity, cytolysis, vacuolization, altered viscosity of protoplasm, and altered permability of the cell wall.

It should be pointed out that many of these effects can be duplicated individually with other types of stimuli. However, the entire gamut of effects cannot be reproduced by any single chemical agent. (It is interesting to note that a group of chemical agents that come close to duplicating radiatio effects are the nitrogen mustards.)

Recovery Period

Following exposure to radiation, recovery can and does take place to a certain extent. This is particularly manifest in the case of the short-term effects; i.e., those appearing within a matter of days or weeks after exposure. There is, however, a residual damage from which no recovery occurs, and it is this irreparable injury which can give rise to later long-term effects.

DETERMINANTS OF BIOLOGICAL EFFECTS

The Dose-Response Curve

For any biologically harmful agent, it is useful to correlate the dosage administered with the response or damage produced. "Amount of damage" in the case of radiation might be the frequency of a given abnormality in the cells of an irradiated animal, or the incidence of some chronic disease in an irradiated human population. In plotting these two variables, a dose-response curve is produced. With radiation, an important question has been the nature and shape of this curve. Two possibilities are illustrated in Figures 1 and 2.

Figure 1 is a typical "threshold" curve. The point at which the curve intersects the abscissa is the threshold dose; i.e., the dose below which there is no response. If a short-term and easily observable radiation effect, such as reddening of the skin, is taken as "response," then this type of curve is applicable. The first evidence of the effect does not occur until a certain minimum dose is reached.

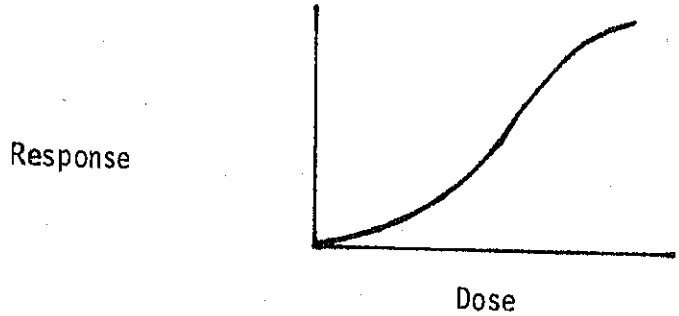

Figure 1

Figure 2 represents a linear, or nonthreshold relationship, in which the curve intersects the abscissa at the origin. Here any dose, no matter how small, involves some degree of response. There is some evidence that the genetic effects of radiation constitute a nonthreshold phenomenon, and one of the underlying (and prudent) assumptions in the establishment of radiation protection guides and in radiation control activities in public health programs has been the existence of a nonthreshold effect. Thus some degree of risk is assumed when large populations of people are exposed to even very small amounts of radiation. This assumption often makes the establishment of guidelines for acceptable radiation exposure an enormously complex task, since the concept of "acceptable risk" comes into play, in which the benefit to be accrued from a given radiation exposure must be weighed against its hazard.

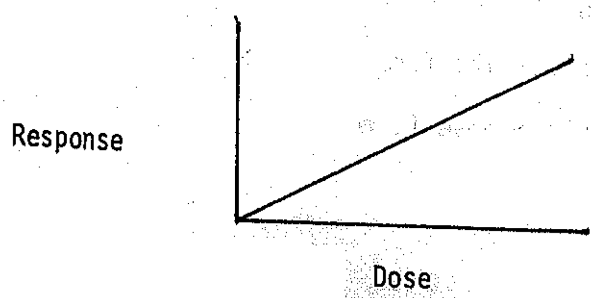

Figure 2

Rate of Absorption

The rate at which the radiation is administered or absorbed is most important in the determination of what effects will occur. Since a considerable degree of recovery occurs from the radiation damage, a given dose will produce less of an effect if divided (thus allowing time for recovery between dose increments) than if it were given in a single exposure.

Area Exposed

Generally when an external radiation exposure is referred to without qualification as to the area of the body involved, whole-body irradiation is assumed. The portion of the body irradiated is an important exposure parameter because the larger the area exposed, other factors being equal, the greater the overall damage to the organism. Even partial shielding of the highly radiosensitive blood-forming organs such as the spleen and bone marrow can mitigate the total effect considerably. An example of this phenemenon is in radiation therapy, in which doses which would be lethal if delivered to the whole body are commonly delivered to very limited areas, e.g., to tumor sites.

STAGES IN THE ACUTE RADIATION SYNDROME

When single radiation doses over 100 rads are delivered rapidly to the entire body, severe consequences result in the symptoms of "radiation sickness." These symptoms are properly called the Acute Radiation Syndrome. In the same manner as other biological effects, these symptoms may be classified according to a typical time sequence including a latent period. Four phases are identified as follows:

Prodrome

This is the initial phase of the syndrome, and is usually characterized by nausea, vomiting, and malaise. It may be considered analogous to the prodrome stage in acute viral infections, in which the individual is subject to nonspecific systemic reactions.

Latent Stage

During this phase, which may be likened to the incubation period of a viral infection, the subjective symptoms of illness may subside, and the individual may feel well. Changes, however, may be taking place within the blood-forming organs and elsewhere which will subsequently give rise to the next aspect of the syndrome.

Manifest Illness Stage

This phase reflects the clinical picture specifically associated with the radiation injury. Among the possible signs and symptoms are epilation, fever, infection, hemorrhage, severe diarrhea, prostration, disorientation, and cardiovascular collapse. Which, if any, of the foregoing phenomena are observed in a given individual is largely dependent upon the radiation dose received. The various forms of illness are discussed below.

Recovery or Death

Relation of Dose to Type of Acute Radiation Syndrome

Recalling the different sensitivities of various kinds of cells, one can predict roughly the biological systems which will be affected as radiation

dose increases. At relatively low doses, 75 to 125 rads, for example, the most likely cells to be injured are those with greatest sensitivity; i.e., immature white blood cells of lymph and bone marrow, so that the observable effects during the manifest illness stage would relate to these cells; one would thus expect to observe fever, infection, and hemorrhage. This is known as the hematopoietic form of the acute radiation syndrome.

At higher doses, usually over 600 rads, cells of somewhat lower sensitivity will be injured. Of particular importance are the epithelial cells which line the gastrointestinal tract, for when these are destroyed, a vital biological barrier is broken down. As a result, there may be fluid loss, overwhelming infection, and severe diarrhea in this gastrointestinal form of the acute radiation syndrome.

In the cerebral form, which may result from doses of 10,000 rads or more, the relatively resistant cells of the central nervous system are damaged, and the affected individual undergoes a rapid illness, characterized by disorientation and shock.

Considering the large degree of individual variation which exists with respect to radiation injury, it is difficult to assign a precise dose range to each of the above forms of the syndrome. The following generalizations, however, may serve to provide a rough indication of the kinds of doses involved. At 50 rads or less, ordinary laboratory or clinical methods will show no indications of injury. At 100 rads, most individuals show no symptoms, although a small percentage may show mild blood changes.

At 200 rads, most persons show definite signs of injury; this dose level may prove fatal to those individuals most sensitive to the effects of radiation. At 450 rads, the median lethal dose has been reached, and 50 percent of exposed individuals will succumb. Approximately 600 rads usually marks the threshold of the gastrointestinal form of the acute radiation syndrome, with a very poor prognosis for all individuals involved; a fatal outcome may well be certain at 800 to 1,000 rads. (For a detailed account of the Acute Radiation Syndrome, including symptomatology, laboratory findings, diagnosis, and patient management, see: Thoma, George E., and Wald, Niel, "The Diagnosis and Management of Accidental Radiation Injury," Journal of Occupational Medicine, 1: 421-427, August 1959.)

Summary

The Acute Radiation Syndrome represents the signs and symptoms which result from large doses of radiation, generally over 100 rads, delivered to a major portion of the body; it is important to recall that this type of injury occurs only when the dose is received over a short period of time. The total effect may vary from mild to transient illness to death.

Because of the variation in susceptibility to radiation injury which exists among different individuals, it is extremely difficult to predict with accuracy the degree of effect in a given person, even when the dose is known. Within certain broad ranges, however, certain effects may be correlated with various dose levels on a population basis.

The course of the syndrome may vary from hours to several weeks. This time element is generally related to the radiation dose; other factors being equal, the duration of the various phases of the syndrome is inversely proportional to the amount of radiation received, with a rapid, fulminating illness being characteristic of very high doses.

LONG-TERM EFFECTS

Long-term effects of radiation are those which may manifest themselves years after the original exposure. The latent period, then, is much longer than that associated with the acute radiation syndrome. Delayed radiation effects may result from previous acute, high-dose exposures or from chronic low-level exposures over a period of years. From the standpoint of public health significance, the possibility of long-term effects on the large number of people receiving low, chronic exposures is cause for greater concern than the short-term radiation effects from acute exposures which involve only a few individuals.

It should be emphasized that there is no unique disease associated with the long-term effects of radiation; these effects manifest themselves in human populations simply as a statistical increase in the incidence of certain already existing conditions. Because of the low normal incidence of these conditions, it is usually necessary to observe large populations of irradiated persons in order to measure this kind of increase, and employ biostatistical and epidemiologic methodology. In addition to the large number of people needed for human studies of long-term radiation effects, the situation is further complicated by the latent period; in some cases, a

radiation-induced increase in a disease may go unrecorded unless the study is continued for many years.

It should also be noted that although it is possible to perform true experiments with animal populations, in which all factors with the exception of radiation exposure are kept identical in study populations, human data is limited to "second hand" information, accrued from populations which have been irradiated for reasons other than radiobiological information. It is often the special characteristics of irradiated human populations, i.e., the presence of some preexisting disease, which make it extremely difficult to draw meaningful conclusions when these groups are compared with non-irradiated ones.

Despite the above difficulties, many epidemiologic investigations of irradiated human beings have provided convincing evidence that ionizing radiation may indeed result in an increased risk of certain diseases long after the initial exposure. This information supplements and corroborates that gained from animal experimentation which demonstrates these same effects.

Among the long-term effects thus far observed have been somatic damage, which may result in an increased incidence of cancer, embryological defects, cataracts, and lifespan shortening; and genetic mutation, which may adversely affect many generations after the original radiation damage.

Embryolgical Effects

Considering the fact that immature, undifferentiated, and rapidly dividing cells are highly sensitive to radiation, it is not surprising that embryonic and fetal tissues are readily damaged by relatively low doses of radiation. It has been shown in animal experiments that deleterious effects may be produced with doses of only 10 rads delivered to the embryo. There is no reason to doubt that the human embryo is equally susceptible.

The majority of the anomalies which are produced by prenatal irradiation involve the central nervous system, although the specific type of damage is related to the dose and to the stage of pregnancy during which irradiation takes place. In terms of embryonic death, the very earliest stages of pregnancy, perhaps the first few weeks in the human beings, are most radiosensitive. From the standpoint of practical radiation protection, this very early sensitivity is of great significance, because it involves a stage in human embryonic development in which pregnancy may well be unsuspected. For this reason, the International Committee on Radiological Protection has recommended that routine nonemergency diagnostic irradiation involving the pelvic area of women in the child-bearing years be limited to the 10-day interval following the onset of menstruation. Such precautions would virtually eliminate the possibility of inadvertantly exposing a fertilized egg. This recommendation has been accepted in many countries, including Great Britain, German, Norway, and Denmark, among others. In a few countries, guidelines have also been formulated for therapeutic abortion when pelvic radiation doses during certain stages of pregnancy are estimated to exceed specified limits.

For the production of congenital anomalies in the newborn, irradiation during the period of organogenesis is of greatest importance. This period occurs during approximately the second through the sixth week of human gestation, when pregnancy could still be unsuspected. During this period, embryonic death is less likely than in the extremely early stage, but the production of morphological defects in the newborn is a major consideration.

During later stages of pregnancy, embryonic tissue is more resistant to gross and easily observable damage. However, functional changes, particularly those involving the central nervous system, may result from such late exposures and would be difficult to measure or evaluate at birth. They usually involve subtle alterations in such phenomena as learning patterns and development and may have a considerable latent period before they manifest themselves. There is some evidence that the decreasing sensitivity of the fetus to gross radiation damage as pregnancy progresses may not apply for the leukemogenic effects of prenatal irradiation. Another important factor to be considered in evaluating the radiation hazard during late pregnancy is that irradiation may produce true genetic mutation in the immature germ cells of the fetus for which no threshold dose has been established.

It should be emphasized that radiation is not unique in producing embryological effects and that a growing body of evidence exists which indicates that a host of external insults, including certain drugs, chemicals, and viral infections, also can damage the highly sensitive embryo and fetus.

Human evidence for embryological damage has been found among persons exposed *in utero* at the time of the atomic bombing of Hiroshima. Data obtained from their follow-up through childhood and adolescence into adulthood, in which groups exposed during gestation were compared with each other and with nonexposed controls on the basis of distance from the detonation and stage of pregnancy, shows a growth stunting effect among the exposed, particularly as regards head size, and an increased incidence of mental retardation.

The incidence of these developmental defects correlates well with proximity to the bomb and thus with estimated dose; also, the results further corroborate the increased sensitivity to embryological damage during the first trimester of pregnancy.

Cataractogenic Effects

The fibers which comprise the lens of the eye are specialized to transmit light. Damage to these, and particularly to the developing immature cells which give rise to them, can result in opacities in the lens called cataracts, which, if they are large enough, can interfere with vision. Radiation in sufficiently high doses can induce the formation of cataracts; the required dose for humans, which is difficult to ascertain, probably is in the order of several hundred rads for x or gamma rays, and 1/5 to 1/10 of this for neutron irradiation.

Human evidence for radiation cataractogenesis is derived mainly from a relatively small number of workers inadvertently exposed to large doses of

radiation to the eye, including several nuclear physicists working with cyclotrons; patients exposed to therapeutic radiation (sometimes from radium plaques applied to the eye); and Japanese atomic bomb survivors who were heavily irradiated.

Lifespan Shortening

In a number of animal experiments, radiation has been demonstrated to have a lifespan shortening effect. The aging process per se is complex and largely obscure, and the exact mechanisms involved in this effect are as yet uncertain. Irradiated animals in these investigations appear to die of the same diseases as the non-irradiated controls, but they do so at an earlier age. How much of the total effect is due to premature aging and how much to an increased incidence of radiation-induced diseases is still unresolved.

Mechanisms - A number of theories have been proposed to account for the phenomenon of aging in general, and for the aging effects of radiation in particular. One theory is that a variety of extrinsic insults produce tissue damage in organisms, some of which is reparable and some of which is irreparable. The irreparable, or residual components of various insults to the organism (infections, trauma, etc.) are additive and cumulative, and when a certain critical amount of injury has accumulated, the organism dies. Because irradiation is one of the agents which can produce such injury, irradiated animals arrive at a lethal accumulation sooner than do the non-irradiated controls. Another theory proposes that

radiation exerts its lifespan shortening effect by producing somatic mutations in the cells, which lower the organism's ability to function properly. It further states that organs having cells which seldom, if ever, divide are affected most by these mutations, and play a major part in the aging process.

Human Evidence - A study of the possible lifespan shortening effect of radiation in British radiologists yielded negative results. On the other hand, an investigation of American radiologists, as compared with physicians not using radiation, appeared to show that radiologists die approximately 5 years sooner than their non-radiological counterparts. A follow-up study, however, indicated that proper age correction factors had been ignored in the original work and that when these were applied, the lifespan differences disappeared. A more recent American study, in which death rates from various causes were established for radiologists and for two control groups, consisting of physicians who used radiation somewhat and those who did not use it at all, seems to show a true lifespan shortening effect among the radiologists. An association, of course, between two phenomena (in this case, being a non-radiologist) does not necessarily indicate that one is a cause of the other, and recalling the caution with which epidemiologic studies must be interpreted, one might propose explanations for the association other than that the radiation causes the shortened lifespan. It is conceivable, for example, that those individuals choosing radiology as a specialty could be somewhat less healthy as a group than those selecting other fields, and thus a slightly shorter lifespan among the former would not necessarily relate to their radiation exposure. The authors have

considered such alternative explanations of the data, however, and, because of certain strengthening factors in their findings, they nonetheless hold that a true lifespan shortening effect was operative. An important finding in this study, which helps to support the general adequacy of current occupational radiation protection guidelines, is that the excess risk of death among the radiologists is largely confined to those who practiced during the earlier years of x-ray use when safety practices were more lax and occupational exposures among radiologists were presumably much higher than today.

CARCINOGENIC EFFECTS

With proper selection of animal species and strains, and of dose, ionizing radiation may be shown to exert an almost universal carcinogenic action, resulting in tumors in a great variety of organs and tissues. There is human evidence as well that radiation may contribute to the induction of various kinds of neoplastic diseases, including carcinomas, sarcomas, and other tumors.

Possible Mechanisms

It should be made clear that even with high doses of radiation, most irradiated individuals will not suffer long-term consequences despite the fact that the incidence of certain diseases, such as leukemia and other forms of cancer, may be increased many fold. The explanation lies in the fact that most diseases are probably "caused" by the simultaneous interaction of several factors, and that the presence of some of these factors without the others may not be sufficient to induce the disease.

Radiation, like other chemical and physical agents which are considered carcinogenic, may be only one of a number of interacting factors which, in a given individual, must be present in order to result in the disease.

Among the tentative explanations thus far proposed for the carcinogenic action of radiation are the following:

1. The essential factor in the production of cancers may be a virus which attacks normal cells by injecting itself into the cell nucleus. The genetic material of the virus, now within the host cell, stimulates the cell to reproduce wildly, thus initiating the neoplastic growth. The virus, it would seem, is ubiquitous and even may be passed from mother to fetus during prenatal life. It would follow, then, that normal cells have a natural mechanism whereby the action of these viruses is resisted; it is possible that radiation and other carcinogenic agents may activate the latent virus or interfere with the cell's resistance. In this case, the presence of the virus in the tissue would be the primary, initiating event, and the radiation would act as a promoting agent.

2. Certain diseases, among them leukemia, have been associated with specific chromosome aberrations. It may be that radiation damage can produce these abnormalities in the chromosomes and that these changes in turn initiate the disease.

3. Radiation can produce mutations in the somatic cells as well as the germ cells, and it may be that a sufficient accumulation of mutations in a colony of cells can result ultimately in the kind of uncontrolled growth which results in cancer. The somatic mutation concept is an attractive one since it provides a means by which to relate both the carcinogenic effects of radiation and aging. Somatic mutations probably occur constantly at a low rate in all organisms and the resultant damage accumulates gradually in the affected tissues. When the level of malfunction or damage reaches a critical point, cell death or carcinogenesis could occur. Radiation, like other harmful agents, may accelerate the rate at which these mutations occur, thus hastening the death of the organism or the production of cancers.

4. When radiation doses are large enough to destroy a portion of the cells in an organ, the surviving cells, many of which may have undergone mutations as a result of the radiation exposure, are stimulated to rapid reproduction in order to replace the missing ones (Figure 3). This resulting rapid division may be a concomitant factor in cancer production. In the somatic chromosome abberation or mutation processes, the radiation-induced change may be the primary or intiating event, with other factors playing a contributory or promoting role.

5. As a result of the irradiation of water-molecules, which are abundant in all living cells, certain short-lived but potent damaging agents called free radicals are formed and may play an important role in both cancer and aging (Figure 4). There is some evidence that these

radicals are generated continually at a low rate as a by-product of certain normal biochemical reactions in living cells, and that radiation simply accelerates their formation.

None of the above speculations need exclude the others. That cancer, mutations, and aging are interrelated seems reasonably clear, but the precise mechanisms involved have yet to be elucidated. One theory ties together several phenomena and holds that cancer evolves when a genetic mutation which predisposes an individual to cancer interacts during his lifetime with a sufficiently large number of accumulated somatic mutations (which can be produced by radiation) in the presence of a triggering agent, which could be a virus.

HUMAN EVIDENCE

Both empirical observations and epidemiologic studies of irradiated individuals have more or less consistently demonstrated the carcinogenic properties of radiation. Some of these finds are summarized below.

Radium Dial Painters. Early in this century, when long-term radiation effects were little recognized, luminous numerals on watches and clocks were painted by hand with fine sable brushes, dipped first in the radium-containing paint and then often tipped on the lips or tongue. Young girls commonly were employed in this occupation. Years later, studies of these individuals who had ingested radium paint have disclosed an increased incidence of bone sarcomas and other malignancies, resulting from the burdens of radium which had accumulated in their bones.

Radiologists and Dentists. Some early medical and dental users of x-rays, largely unaware of the hazards involved, accumulated considerable doses of radiation. As early as the year 1910, there were reports of cancer deaths among physicians, presumably attributable to x-ray exposure. Skin cancer was a notable finding among these early practitioners; dentists, for example, developed lesions on the fingers with which they repeatedly held dental films in their patients' mouths.

Uranium Miners. Early in this century, certain large mines in Europe were worked for pitchblende, a uranium ore. Lung cancer was highly prevalent among the miners as a result of the inhalation of large quantities of airborne radioactive materials. It was estimated that the risk of lung cancer in the pitchblende miners was at least 50 percent higher than that of the general population.

Modern mining conditions have greatly improved. Nonetheless, recent studies have indicated a slight but statistically significant excess risk of lung cancer even among contemporary American uranium miners.

Atomic Bomb Survivors. One of the strongest supports for the concept that radiation is a leukemogenic agent in man comes from the epidemiologic studies of the survivors of the atomic bombing in Hiroshima. Survivors exposed to radiation above an estimated dose of approximately 100 rem showed a significant increase in the incidence of leukemia. In addition, leukemia incidence correlated well with the estimated dose (expressed as distance from the detonation) thus strengthening the hypothesis that the excess leukemia cases were indeed attributable to the radiation exposure. There is also some indication of an increase in thyroid cancer among the heavily irradiated survivors.

Ankylosing Spondylitis Patients. Ankylosing spondylitis, a progressively disabling arthritic disease of the spine, can be treated with large x-ray doses delivered to the vertebrae to slow the progress of the disease and to relieve symptoms. Persons thus treated accumulated large doses of radiation to the bone marrow. A study of a large population of such persons revealed a much higher incidence of leukemia than might be expected in the general population. That the observed leukemias were probably due to the radiation is attested to by a subsequent study in which the leukemia incidence for patients with arthritic diseases not treated with x-rays was ascertained; the authors conclude that the irradiation was probably a major factor in the excess leukemia found among the x-ray-treated patients.

Children Irradiated for Thymus Enlargement. Many young children with respiratory distress were diagnosed in former years as having enlarged thymus glands and were treated with therapeutic doses of x-rays to the thymic region at the base of the neck. A number of follow-up studies were performed on these children, and although results varied, it is generally agreed that these persons have experienced a significantly increased incidence of thyroid cancer and other malignancies of the head and neck. Such finds are not limited to thymic irradiation; further studies have demonstrated excess thyroid cancers and other head and neck malignancies as a result of childhood irradiation to this area of the body for the treatment of a wide variety of benign conditions such as enlarged tonsils and adenoids, acne, etc. Radiation therapy for benign conditions is no longer approved.

Polycythemia Patients. Polycythemia vera is a disease characterized by an excess of red blood cells which can be treated by the administration of phosphorus-32 internally. An epidemiologic study of patients thus irradiated seems to indicate a considerable excess of subsequent leukemias, compared with a control population consisting of non-irradiated polycythemia patients.

Patients Treated by Pneumothorax. A link between high doses of radiation to the chest and breast cancer was discovered in a survey of women who had been treated for tuberculosis by artificial pneumothorax, a procedure which consisted of intentionally collapsing the affected lung for a period of time and then reinflating it. This was accomplished with the assistance of the fluoroscope, and in many cases the pneumothorax treatment was repeated, sometimes more than 100 times. The patient was often positioned in the vertical fluoroscope machine facing the x-ray tube, so that the largest radiation dose was delivered to the anterior surface of the chest. The incidence of breast cancer among these heavily irradiated patients was found to be 4 to 8 times the expected rate for this disease. Further, the investigator was able to show a correlation between the side of the chest receiving the treatment and the affected breast.

Children of Mothers Irradiated During Pregnancy. A pioneering study in this area purported to show an increased risk of leukemia among young children if they had been irradiated in utero as a result of pelvic x-ray examination of the mother. Mothers of leukemic children were questioned as to their radiation histories during pregnancy with the child in question,

and these responses were compared with those of a control group, consisting of mothers of healthy playmates of the leukemic children. Originally this work received much criticism, based partly on the questionnaire technique used to elicit the information concerning radiation history. It was believed that differences in recall between the two groups of mothers might have biased the results. A larger subsequent study designed to correct for the objections to the first one corroborated its essential findings, and established the leukemogenic effect on the fetus of prenatal x-rays.

It should be noted that the investigations presented thus far which demonstrate the carcinogenic properties of radiation involve large doses, such as those received in therapeutic x-ray procedures, with the exception of these childhood leukemia investigations. Here, doses of radiation are low, in the diagnostic radiographic range. Such findings bear out the high sensitivity of embryonic tissues to radiation damage.

In evaluating human studies of the kind described above, two important concepts should be borne in mind:

1. Because these studies were not designed as radiobiological experiments in which all factors are held constant with the exception of radiation exposure, caution is required before the association between radiation and some later disease can be labeled as a cause-effect relationship. This is particularly true when the study group consists of patients irradiated for some disease or abnormality, since the question arises as to whether the abnormality itself might not account for the later

disease rather than the irradiation. Sometimes further studies or the selection of a proper control group with which to compare the irradiated subjects can help to resolve these doubts. For example, in the spondylitis investigation, a valid question arose as to whether the disease itself might predispose the patient to develop leukemia later. A follow-up study which ascertained the leukemia incidence among non-irradiated rheumatic patients, helped to answer this question. The same question might have arisen in the polycythemia study, except that the control group in this instance consisted of persons with the disease who had not been treated with radiation. Doubts concerning the studies of children with thymic irradiation could have been forestalled, had the control group consisted of children with diagnosed thymic enlargement who had not been treated with x-rays. It was not possible, however, to select such a control group; instead healthy siblings or cancer incidence from general population statistics were employed. Thus, although the weight of evidence in these studies points toward true radiation carcinogenesis, there is room for speculation as to whether the infants with enlarged thymus glands might not have been at least somewhat predisposed to the development of malignant diseases. Even the studies of the relationship of prenatal x-ray examinations to childhood leukemias have been subject to the same kind of question; e.g., whether the special characteristics of the mothers and children in question which necessitated the pelvic x-rays in the first place might not be a predisposing factor in the development of leukemia, irrespective of or in addition to the radiation received. Despite

these reservations, all of the above studies, when taken together, comprise an impressive accumulation of evidence indicating that ionizing radiation is a true carcinogen in man.

2. Assuming that studies such as these are valid, the question arises as to their practical implications. Even in investigations such as the spondylitis and polycythemia studies in which roughly a ten-fold increase in leukemia was observed, the additional risk to an irradiated individual remains small because of the relatively low normal incidence of leukemia. The small but real increase in risk to the individual calls for an intelligent balancing, in each case, of the benefits to be accrued from the radiation exposure and the concomitant hazard. Valuable therapeutic and diagnostic x-ray techniques which are of great benefit to patients cannot be abandoned because of the risk of delayed harmful effects; on the other hand, if the same diagnostic information or theapeutic results can be obtained using techniques which reduce radiation exposure to the patient, or if equally effective nonradiologic procedures which do not involve such risk are available, such methods should be used.

GENETIC EFFECTS

Background - The fertilized egg, which is a single cell resulting from the union of sperm and egg, and which after millions of cell divisions results in a new organism, contains all of the genetic information necessary to produce all of the organs and tissues of the new individual. This information is carried in the nucleus of the fertilized egg on rod-shaped

structures called chromosomes, arranged in 23 pairs. In each pair, one member is contributed by the mother and the other by the father. With each cell division which the rapidly developing embryonic tissue undergoes, all of this information is faithfully duplicated, so that the nucleus in each cell of the new organism contains essentially all of the information. This, of course, includes those germ cells in the new organism which are destined to become sperm and egg, and thus the information is transmitted from one generation to the next. This hereditary information is often likened to a template, or to a code, which is reproduced millions of times over with remarkable accuracy. It is possible to damage the hereditary material in the cell nucleus by means of external influences, and when this is done, the garbled or distorted genetic information will be reproduced just as faithfully when the cell divides as was the original message. When this kind of alteration occurs in those cells of the ovaries or testes which will become mature sperm and egg, it is referred to as genetic mutation; if the damaged sperm or egg cell is then utilized in conception, the defect is reproduced in all of the cells of the new organism which results from this conception, including those which will become sperm or egg, and thus whatever defect resulted from the original mutation can be passed on for many generations.

Most geneticists agree that the great preponderance of genetic mutations are harmful. By virtue of their damaging effects, they can be gradually eliminated from a population by natural means, since individuals afflicted with this damage are less likely to reproduce themselves successfully than

normal individuals. The more severe the deficit produced by a given mutation, the more rapidly it will be eliminated, and vice-versa; mildly damaging mutations may require a great many generations before they gradually disappear.

As a balance to this natural elimination of harmful mutation, fresh ones are constantly occurring. A large number of agents have mutagenic properties, and it is probably that our current knowledge includes just a fraction of these. In addition, it may be that mutations can arise within the germ cells of an organism without external insult; free radicals, which may be produced as a natural by-product of normal metabolic reactions in the body, may have a mutational effect. Among the various external influences which have been found to be mutagenic are a wide variety of chemicals, certain drugs, and physical factors such as elevated temperatures and ionizing radiation. Natural background radiation probably accounts for a small proportion of naturally occurring mutations. For man, it has been estimated that background radiation probably produces less than ten percent of these. Man-made radiation, of course, if delivered to the gonads, can also produce mutations, over and above those which occur spontaneously. Radiation, it should be noted, is not unique in this respect, and is probably one of a number of man-made environmental influences which is capable of increasing the mutation rate.

<u>Observing Mutations</u> - Measuring changes in the normal mutation rate in humans is extremely difficult for several reasons. First, the majority of mutations are recessive; that is, their full effects do not manifest themselves in an individual unless he carries the same mutational defect

in the same location on a given pair of chromosomes, i.e., unless both his mother and father were afflicted with the same kind of genetic damage. It can be seen from this that it might take many generations after a genetically damaging event occurred in a population before enough individuals carrying the recessive mutation mated with one another to produce offspring who would demonstrate overt damage. Secondly, contrary to popular impression, the damage produced by most mutations is subtle in its effects and difficult to measure. Mutations, for example, may result in a slightly altered metabolism, in which there is a less efficient utilization of certain nutritional elements, or a slightly greater predisposition to a given disease, or a slightly lower intelligence than would otherwise have been attained. Adding to this is the difficulty encountered in extricating true genetic phenomena from other influences which may produce the same results. It would be most difficult, for example, to determine whether an individual's predispostion to heart disease were due to a subtle genetic defect in his cardiovascular system or to environmental stresses such as diet or occupation, or to personality and developmental factors in childhood, etc.

Despite these difficulties, it is possible to observe fluctuations in the mutation rate if large enough populations are available for close study. Certain diseases, for example, have been linked to specific genetic defects, and an increase or decrease in the incidence of these diseases would indicate a concomitant change in the mutation rate. Certain mutations are lethal; they are highly damaging and result in intrauterine death. Other factors being equal, significant fluctuations in the incidence of these

deaths in a population might serve as a rough barometer of changing mutation rates. Observing a population for evidence of genetic mutations can be likened to watching an iceberg; most of the iceberg is invisible, with only a small portion above the water. Changes in the size of the observable part serve to give some indication of the more significant changes taking place beneath the surface. (For a discussion of the difficulties and techniques in finding and evaluating genetic radiation damage, see Chapter 7, "The Quantitative Assessment of Hereditary Damage Induced by Radiation," by James and Newcombe, in Progress in Medical Genetics, Volume 3, Grune and Stratton, Inc., New York, 1964.)

Even in the first generation after a population has been exposed to a possibly mutagenic event, it is possible to observe the effects of certain kinds of mutations. Dominant mutations, i.e., those which manifest their full effects even when only one parent carries the mutation, may be evident in the offspring. Those which are also lethal will appear as an increase in intrauterine deaths. There is a particular kind of recessive mutation which can also be observed in the first generation, the sex-linked mutation. Of the 23 pairs of chromosomes in the fertilized egg, one pair determines the sex of the offspring. In this pair, females carry two full-sized chromosomes, called X-chromosomes, while males carry one X-chromosome and one Y-chromosome, which is much smaller and which probably does not carry a full compliment of genetic information. If a recessive mutation arises on one of the X-chromosomes of the mother, female offspring who inherit it, but who have the benefit of the matching normal X-chromosome of the father, will not demonstrate this recessive characteristic. Male offspring however,

to whom the mother has contributed this defective X-chromosome, have only the small Y-chromosome contributed by the father to offset the deficit, and as a result, the damage will appear in these males despite its having been produced by a recessive mutation. Recessive sex-linked mutations of this kind which are also lethal will thus show up as an increase in the number of intrauterine deaths among boys and not among girls. This provides a useful yardstick for assessing genetic damage in an irradiated population, for if a subpopulation is selected in which mothers have been irradiated and fathers have not, then a lowering in the percentage of boys born versus girls, i.e., a reduction in the <u>sex-ratio</u>, might be an indicator of genetic damage.

<u>Animal Evidence</u> - The mutagenic properties of ionizing radiation were first discovered in 1927, using the fruit fly as the experimental animal. Since that time, experiments have been extended to include other species, and a great deal of recent investigation has been carried out on the mouse. Animal experimentation remains our chief source of information concerning the genetic effects of radiation, and as a result of the intensive experimentation which has been carried out during recent years, certain generalizations may be made. Among those of health significance are: (1) that there is no indication of a threshold dose for the genetic effects of radiation, i.e., a dose below which genetic damage does not occur, and (2) that the degree of mutational damage which results from radiation exposure seems to be dose-rate dependent, so that a given dose is less effective in producing damage if it is protracted or fractionated over a long period of time.

Human Evidence - A major human study on genetic effects has concerned the Japanese atomic bomb survivors. As the index of a possible increase in the mutation rate, the sex-ratio in the offspring of certain irradiated groups (families, for example, in which the mother had been irradiated but the father had not) was observed, using the approach described earlier. Assuming that some of the mutational damage in the mothers would be recessive, lethal, and sex-linked, a shift in the sex-ratio among these families might be expected in the direction of fewer male births than in completely non-irradiated groups, and this seemed to be the case in early reports. Later evaluation of more complete data however, did not bear out the original suggestion of an effect on the sex-ratio.

The preconception radiation histories of the parents of leukemic children as compared with those of normal children was a part of the subject of another investigation. From the results, it would appear that there is a statistically significant increase in leukemia risk among children whose mothers had received diagnostic x-rays during this period. The effect here is apparently a genetic rather than an embryologic one, since the irradiation occurred prior to the conception of the child.

A somewhat similar study ascertained the radiation exposure histories of the parents of children with Mongolism; most of this exposure, too, was prior to the conception of the child. A significantly greater number of the mothers of Mongoloid children reported receiving diagnostic fluoroscopy and x-ray therapy prior to the birth of the Mongoloid child than did mothers of normal children comprising a control group.

The findings of these two studies serve to provide additional evidence that ionizing radiation is a mutational agent in man. On the other hand, they can be viewed with the same kind of reservations as were explained previously; i.e., there could be significant differences to begin with between populations of people requiring x-rays and those not requiring x-rays. These differences alone might account for a slightly higher incidence of leukemia or Mongolism in the offspring of the former group, irrespective of the radiation received.

Health Significance of Genetic Mutations - Recalling the previous discussion concerning the natural elimination of harmful mutations and the simultaneous introduction of fresh ones into a population, the total number of mutations present may be likened to the water in a tank in which the in-flow at the top represents new mutations and out-flow at the bottom respresents the eliminations of old mutations. The water level does not necessarily remain constant; if the rate at which new mutations are producec exceeds that at which old ones are discarded, the pool of mutations grows larger. The reverse is true if the output exceeds the input, with a resultant lowering of the pool. With contemporary human populations, it is highly desirable to keep the level of the mutational pool as low as possible, since the pool largely represents diseases and defects which tend to lower overall biological fitness. However, two factors unique to modern life may tend to increase the level. First, human populations are being exposed to a greater and greater number of potential mutagens as a result of a progressive increase in the variety and quantity of man-made chemical and physical agents which are a product of our technological advances.

Secondly, modern medical knowledge and techniques result in the salvage of more and more individuals with genetic defects so that they may reproduce themselves, thus distributing these defects to an ever larger number of people. In the face of these factors which tend to increase the mutational load in the world's population, it is all the more important, if the level of the pool is to be kept at a minimum, to make every effort to maintain the influx of new mutations as small as possible. Considering the potent mutagenic properties of ionizing radiation, the goal then is clear: to avoid any unnecessary irradiation of the gonads.

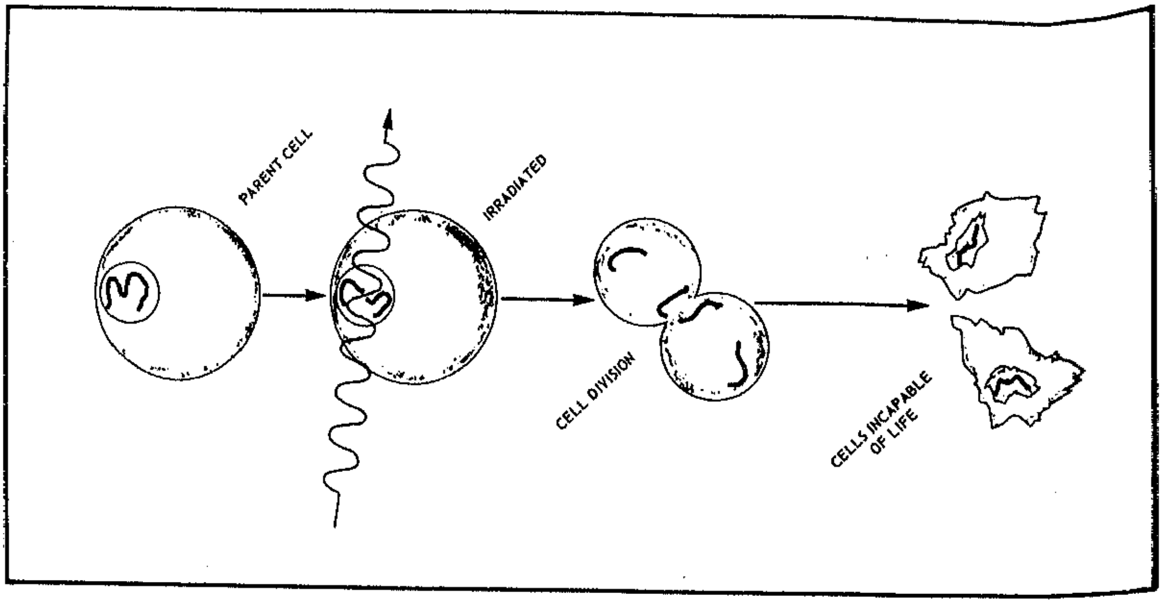

Figure 3. Target Theory Damage

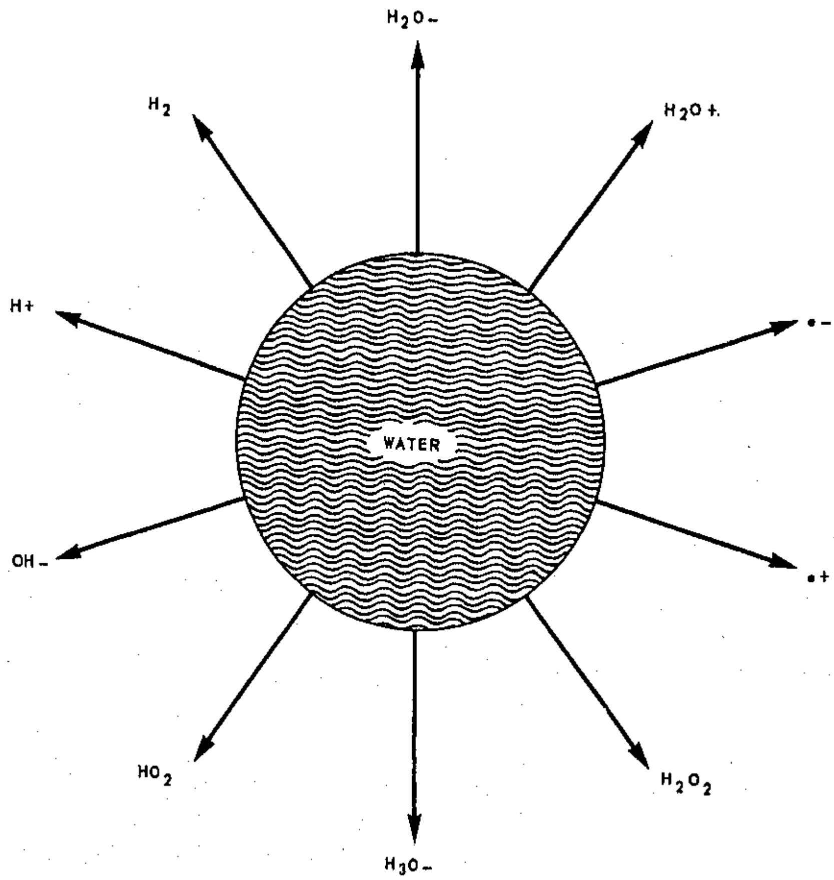

Figure 4. Products of Irradiated Water

SECTION 8

SOURCES OF RADIATION EXPOSURE

SOURCES OF RADIATION EXPOSURE

The human race has always been exposed to ionizing radiation of cosmic origin and from natural sources in the environment and within the body. A representative distribution of the dose received from this source is shown in Table 1.[1] The indicated total of 125 millirems per year is an estimated average figure for the United States. The exact amount varies with locality because of differences in the amounts of natural radioactive material present and variation in the intensity of cosmic rays with altitude and latitude. For example, cosmic radiation increases by a factor of 2 in going from sea level to 10,000 feet and by about 15 percent in going from 0° to 50° geomagnetic latitude. Reported natural background radiation levels for the United States range from about 90 to 200 millirems per year. In some parts of the world, such as the Kerala regions of India and the States of Minas Gerias and Espirito Santo of Brazil, much higher levels prevail.[2] Radiation from thorium-bearing monazite sands in these areas makes the external environmental absorbed dose 10 to 30 times the world average. Man has reached his present state of development in the presence of background radiation; it is apparently an amount with which he can live compatibly.

Today, background radiation is only one of many sources to which the world's population is exposed. Radiation-generating machines and radioactive materials present in many phases of the environment constitute the principal manmade sources.

X RAYS

X-ray machines are finding widespread use in industry, medicine, commerce, and research. All such uses are potential sources of exposure.

Medical and Dental Use

Currently, over 200,000 medical and dental x-ray units are used in the United States for diagnosis and therapy. Some 98,000 of these units are used by dentists, with 100,000 to 130,000 employed by medical practitioners, radiologists, hospitals, and clinics.[3]

Surveys indicate that a substantial number of medical-technical personnel are occupationally exposed in the operation of these machines. In addition, a considerable portion of the general population is exposed during diagnostic and therapeutic procedures. On the average, over half the people in the United States are exposed to x-rays for medical or dental purposes each year. In 1964, the number of persons x-rayed[4] was approximately 108 million--12 million of whom had more than one category of x-ray procedure which results in the following distribution:

66 million for radiographic procedures
46 million for dental diagnosis
8 million for fluoroscopy
600 thousand for x-ray therapy

Industrial Use

Industrial x-ray devices include primarily: (1) radiographic and fluoroscopic units used to determine defects in castings, fabricated structures and welds, and (2) fluoroscopic units used to find foreign material in such

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items as food products. At present, there are slightly more than 10,000 industrial radiographic installations in the United States.[3]

Commercial Use

A major use of x-ray machines has been in shoe-fitting. In 1950, there were almost 10,000 such units in operation in the United States.[5] Health authorities considered such exposures unnecessary, and the application of x-ray fluoroscopes in shoe-fitting has been banned or severely restricted in most states. The number remaining in operation today is small.

Research Use

High-voltage x-ray machines and particle accelerators are familiar features of research laboratories in universities and similar institutions. In 1941, there were only 16 cyclotron laboratories in the United States. Today, well over 600 accelerator installations (which include cyclotrons, synchrotrons, van de Graaff generators, and betatrons) are in operation.[3,6] Other x-ray equipment used in research includes diffraction units. Over 4,000 of these units are currently in use.

An emerging source of manmade, machine-produced radiation is the neutron generator. In 1966, there were over 200 of these with about 50 additional units being sold annually. Cathode-ray tubes, high-voltage electronic rectifiers, transmitting valves, and television and image tubes can also be significant sources of x-ray exposure if voltages are high and protection is inadequate.

RADIONUCLIDES

Naturally Occurring

The naturally occurring radionuclide most widely used in medicine and industry is ^{226}Ra. In considering the health aspects of naturally occurring radionuclides such as ^{226}Ra, it should be noted that this radionuclide is not covered by DOE regulations and, in some states, can essentially be purchased on the open market. Recently some states have enacted legislation on registration and licensing of naturally occurring radionuclides.

The history of the application of radium and its daughter product is replete with instances of injury and death. This is particularly true in the radium dial painting industry and in mining operations. Even today, radium continues to be a problem, especially in its medical applications. A recent survey in Georgia(7) revealed that of 210 hospitals contacted, 24 owned or leased radium and 40 more allowed its use in their facilities. For the 24 hospitals, the amount of radium on hand ranged from 50 to 440 milligrams (millicuries) and the numbers of treatments ranged from 1 to 100 per year. On-site surveys showed that 8 of the 24 hospitals had one or more leaking sources. Only 5 routinely performed leak tests.

The national inventory of radium has been estimated at 2,000 grams. About 700 grams can be accounted for as sealed sources. Of the remaining 1300 grams, perhaps 65 to 70 percent has gone into various luminous compounds for use on wrist watches, aircraft, military instruments, etc. The 700 grams

that are identifiable are used in approximately 4,500 facilities: approximately 1,000 hospitals and clinics, 1,700 private practitioners' offices, and about 1,800 industrial research and educational institutions.(8)

Artificially Produced

Radionuclides can be produced on a practical scale by neutron irradiation in reactors, by recovery from fission wastes, or by bombardment of target materials by charged particles in accelerators.

The United States has tremendous reactor production capacity. Large amounts of cesium-137, strontium-90, promethium-147, and other fission products are present in fission wastes at the United States Department of Energy's fissionable materials production sites. The Department has announced that megacurie amounts of a variety of radioisotopes are available for purchase.(9) (See Tables 2 and 3.)(10)

Over 11,000 universities, hospitals, and research laboratories in the United States are using manmade radionuclides for medical, biological, industrial, agricultural, and scientific research and for medical diagnosis and therapy.(3, 11) The U. S. Department of Energy and various state health departments have issued over 3,700 licenses to the medical profession.(3, 11) These licenses authorize medical institutions and private physicians to use radionuclides for the diagnosis and treatment of illness. Over a million people in the United States receive this treatment each year.

Harmful exposure from such radionuclides is possible in their preparation, handling and application, and transportation. Exposures, internal and

external, might also arise through contamination of the environment by wastes originating from the use of these materials.

NUCLEAR REACTOR OPERATIONS

Sources of radiation exposure associated with nuclear reactor operations include the reactor itself, its ventilation and cooling wastes, procedures associated with the removal and reprocessing of its "spent" fuel and the resulting fission product wastes, and procedures associated with the mining, milling, and fabrication of new fuels.

There are nearly thirty power reactors, with approximately ten million kilowatts capacity, now operable or under construction in the United States. An additional 45 nuclear power plants with 33 million kilowatts are planned to be operational by 1976.(12)

The most extensive military application of reactors is for propulsion of Navy ships. At the end of 1967, there were 79 nuclear-powered ships in the active fleet: 75 submarines and 4 surface vessels (the aircraft carrier Enterprise, the cruiser Long Beach, and the guided missile frigates Bainbridge and Truxton). Under construction were 29 additional submarines and negotiations were underway for construction of another nuclear aircraft carrier. Some vessels are powered by more than one reactor. (For example, the aircraft carrier Enterprise has eight nuclear reactors.)(13, 14)

The Navy has also launched a series of TRANSIT navigation satellites powered by plutonium-238 thermoelectric generators.(15) It has also placed a series of nuclear-powered signal-producing devices on the ocean floor in various parts of the world.

Much work has also gone into the theory of atomic-powered flight and space systems development employing isotopic heat and power applications. In addition, there will be the need for more land-based research facilities and reactor-powered research propulsion units.

Many workers are currently engaged in uranium mining and milling operations in this country, primarily in the New Mexico and Colorado Plateau regions. The number of workers involved in the fabrication of new fuels and reprocessing of "spent" fuels is currently on the increase. The predicted activity in terms of curies of fission product wastes from such operations is extensive. In addition to this occupational exposure, the general population is potentially subject to low-level internal and external radiation exposure associated with the possible escape and release of reactor wastes to the environment.

WEAPON TESTING

The worldwide total of nuclear detonations through 1962 is probably over 300. More important than the number of detonations is their energy yield, an indication of the quantity of fission products produced. Information released at the 1959 Congressional "Fallout Hearings" showed that 90 to 92 megaton fission yield equivalent had been released to that date. Table 4[16] summarizes the fission and total yields of atmospheric tests conducted by all nations through 1962. Some radioactive materials from these detonations remain for a time in the upper atmosphere. However, measurable amounts of fallout are widely distributed over the United States causing a temporary average increase in radioactivity throughout the country.

POPULATION DOSE

In expressing radiation exposure, one should specify the part of the body being considered. Because of genetic effects, many people consider the dose to the gonads or reproductive organs of prime importance. Typical exposures from natural background and manmade sources are summarized in Tables 1 and 5.[1]

CONTROL PROCEDURES

With increasing knowledge and experience in radiological health, measures for minimizing radiation exposures have been developed.

X-ray Control

Control procedures for protecting the operators of medical, dental, and industrial x-ray machines consist of limiting the time of exposure, maintaining an adequate distance between the x-ray beam and the operator, and using adequate shielding. Generally, a combination of these three safety measures can restrict the dose to acceptable levels.

In protecting the patient, two important factors are: limitation of the size of the beam through proper coning or collimation, and filtration of the beam to remove soft x-rays which would otherwise be absorbed by the body. Experience has shown that the use of proper filtration can result in a two- to fivefold reduction in the dose to the reproductive organs of the patient; through proper coning, the genetic dose can be reduced by a factor of 200 to 500.[17]

Continued research and widespread medical application of new radiographic techniques in special radiographic procedures and in computerized x-ray

control. Each new technique represents not only added exposure to patient and operator, but a unique problem in evaluating the significance of radiation delivered to limited parts of the body. The great benefits to medicine must be considered before restricting the use of these machines, however.

Radioactive Materials

For radioactive materials, containment and isolation or dilution and dispersion are the main control procedures. Containment and isolation is the method of choice for low-volume high-level wastes; dilution and dispersion is used for large-volume low-level wastes. Intermediate-level wastes are generally handled by a combination of the two approaches; the radioactive material content is concentrated and confined with the decontaminated residue released to the environment. The chemical nature of certain radionuclides makes this combined approach difficult to apply. Examples of intermediate-level wastes are hydrogen-3 and krypton-85--two of the contaminants produced in nuclear reactor operations and fuel reprocessing plants.

Large numbers of patients are administered radioactive materials for diagnostic and therapeutic purposes. While the amounts of activity injected are large in comparison to the levels permitted in industrial wastes, the isotopes used usually have shorter half-lives and lower radiation dose-rates that minimize risk to the patient. Waste products generally may be stored until contamination decays well below detectable levels. Technicians must be trained to handle the concentrated doses and radioactive patients with speed and care to reduce exposure to themselves.

COMMENTARY

For the United States, estimates indicate that medical and dental x-rays contribute about one-third of the current genetic dose to man; natural background accounts for approximately 60 percent; and less than 10 percent arises from nuclear reactor operations, weapons testing fallout, and other manmade sources. When planning control procedures to minimize such exposures, it is important to consider the relationship between the dose and the resulting biological effects.

Such considerations are also uppermost in the minds of those responsible for the establishment of Radiation Protection Guides. Most toxic materials, for example, have a threshold dose which, it is felt, must be exceeded before effects appear. When this is the case, control procedures are straightforward and the primary objective is to keep the dose below the threshold. With ionizing radiation, however, it is believed that even the smallest dose may be capable of producing harmful genetic effects. The same relationship may hold for somatic effects.

Since radiation damage may have no threshold, the philosophy of radiation control generally reflects a weighing of the benefits of the particular radiation application against the risks of the associated exposure. That is, the dose must always be kept below the level at which the harmful effects would be considered to outweigh the benefits.

Based on these considerations, experts have made recommendations for the safe conduct of radiation operations. Guide levels have also been established for the general population. These provide criteria for minimizing

genetic and somatic damage. For health personnel, the challenge is to be familiar with exposure sources, to understand the effects of exposure upon man, and to establish effective control programs which will keep occupational and environmental exposures at minimum levels.

The increasing magnitude of radiation producing sources is shown in Figure 1. Simultaneous with this increase, the recommended maximum permissible levels for radiation exposure, now called Radiation Protection Guides, have decreased sharply.

The currently recommended Radiation Protection Guide for the genetic dose to general population groups is 170 mrem per person per year, exclusive of natural background and the purposeful exposure of patients. Table 5 shows that exposures associated with medical procedures make a significant contribution to the current dose.

TABLE 1.--Representative Distribution of Natural Background Radiation

Source	Dose (mrem/yr) Gonad	Bone Marrow
External		
Cosmic Rays	50	50
Terrestrial*	50	50
Internal		
Potassium	20	15
Radium	1.3	1.6
Lead	0.3	0.4
Carbon	0.7	1.6
Radon	3.0	3.0
TOTAL	125	122

*This is due to the presence in the earth's crust of natural radioactive elements, principally those associated with the uranium, thorium, and actinium decay series and with potassium.

TABLE 2.--Total Distribution (Ci/yr) of Radioactive Material

	Estimated Volume 1962	Estimated Volume 1970	Potential Volume 1962	Potential Volume 1970
Tritium	13,025	16,025	213,000	217,000
Krypton	52	8,501	52	8,501
Promethium	50	--	50	200
Polonium	1,750	2,500	1,750	2,500
Others	--	--	--	--
TOTAL	14,877	27,026	214,852	228,201

TABLE 3.--Product Use (Ci/yr) of Radioactive Material

Use	Estimated Volume 1962	Estimated Volume 1970	Potential Volume 1962	Potential Volume 1970
Direct Purchase Products				
Air ionizers	2	2	125,000	125,000
Portable air ionizers	23	23	75,000	75,000
Anti-static devices	1,750	2,500	1,750	2,500
Auto altimeters	50	--	50	200
Educational kits	<0.2	<0.3	<0.2	<0.3
TOTAL	1,825	2,525	201,800	202,700
Continuous Exposure Products				
Aircraft signs	12,000	16,000	12,000	16,000
Watershed tracers	1,000	---	1,000	1,000
Discriminator tubes	1	1	1	1
Iron ore tracers	--	--	--	--
Petroleum and pipeline interface tracers	--	--	--	--
TOTAL	13,052	24,501	13,052	25,501

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TABLE 4.--Approximate Yields (in Megatons) of Atmospheric Nuclear Tests Conducted by All Nations

Inclusive years	Fission Yield		Total Yield	
	Air	Surface	Air	Surface
1945 to 1951	0.19	0.52	0.19	0.57
1952 to 1954	1	37	1	59
1955 to 1956	5.6	7.5	11	17
1957 to 1958	31	9	57	28
Subtotal	37.8	54	69.2	104.6
1959 to 1960	*	*	*	*
1961	25 †		120	
Subtotal	63	54	189	105
1962	76 †		217	
Total	139	54	406	105

*Test moratorium.
†The small-yield tests conducted in Nevada do not contribute significantly to the worldwide distribution of strontium-90 to which this summary is related.

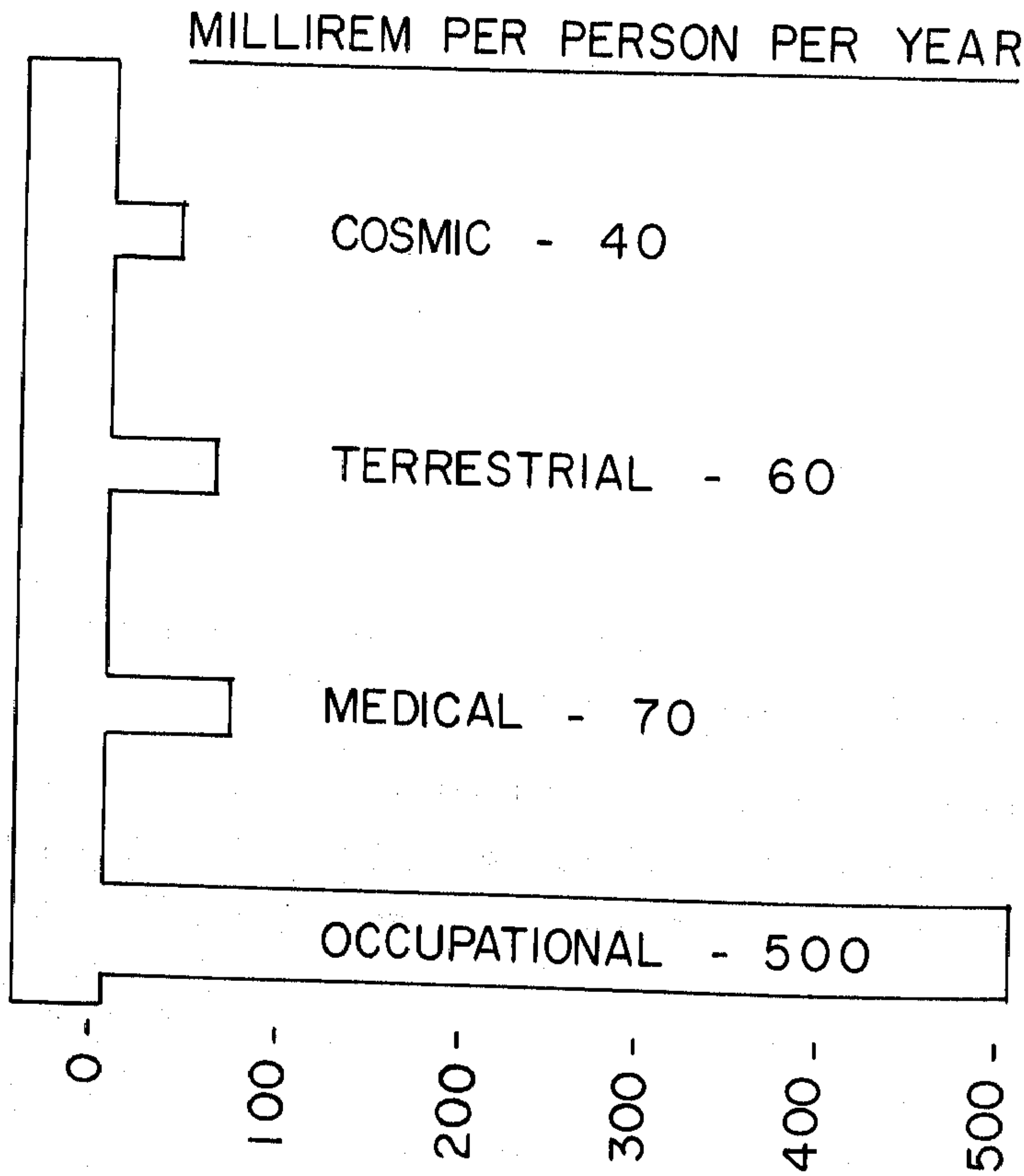
TABLE 5.--Estimated Annual Genetic Doses (rem/yr) from Manmade Radiation

Medicine and dentistry:		
Diagnostic	0.040 - 0.240*	
Therapeutic	0.012	
Internal (radionuclides)	0.001	
Total		0.053 - 0.253
Occupational		0.020
Environs		0.005
Other		0.002
Total		0.080 - 0.280†

*The U.S. Public Health Service x-ray Exposure Study estimated 0.055 rem/yr from medical and dental x-ray.(4)

†In addition, it is estimated that fallout will contribute from 0.002 to 0.05 rem/yr to the genetically significant per capita dose, depending upon the amount of atmospheric nuclear weapons testing.(18)

SOURCES OF RADIATION EXPOSURE



REF: NCRP, NO. 39

FIGURE I

Revised: January 19

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SECTION 9

EXPOSURE GUIDES

Because of the wide range of possibilities, it is difficult to scale levels of radiation one may potentially be exposed to. There is a level no one can escape due to natural sources; there is also the level produced in power reactors and in laboratory experiments presenting the remote possibility of accidental exposures a million times as great. On a human scale, while every exposure must generally be thought to do some small amount of damage, there is a middle ground where we can safely live with radiation for extended periods of time, taking acceptable risks. Exposure guides are proposed to indicate the upper levels of such acceptable exposures measured in units designed to be proportional to the human effect. These exposures are measured in units of rems, or the unit one thousand times smaller, the millirem. Radiation reaches internal body structures both by external irradiation and by ingestion of radioactive substances, many of which concentrate or remain for long periods of time inside the body fluids and tissues.

SOURCES OF RADIATION

The most penetrating source of external radiation comes from cosmic rays, originating in outer space and reaching through the protecting layers of earth's atmosphere, even through the walls of our homes. Depending on elevation, and to a certain extent upon the amount of shelter, these rays result in exposure of 30 to 35 millirems per year. Other rays originating from the soil, rock, and building materials which contain small amounts of radionuclides contribute a similar dose, ranging from 30 to 130 millirem

per year, depending on the local deposits. The internal sources that we can do very little about originated some time during the formation of the earth. While most radioactive substances have decayed away to form stable isotopes, several have such long half-lives that substantial amounts may still be found. Indeed, while some of the sources of natural terrestrial radiation are fixed in solid material, traces of these same elements are also incorporated into compounds contained in the food, water, and air which we ingest. An average of 25 millirem per year is attributable to radioactive forms of uranium, thorium, potassium and carbon. Radiocarbon is continuously produced through the action of cosmic rays on the upper atmosphere, and is therefore replenished and not decaying away.

On a similar scale, medical and dental radiographic procedures, providing many benefits to the large number of people exposed, yearly contribute an additional 50 to 70 millirem to our "inescapable" exposure. Obviously this depends on the individual needs for such medical attention, and several factors modify the risk estimate. First of all, x-rays usually represent only partial body irradiation, and a good technologist greatly reduces patient exposure well below the doses delivered in earlier times using now outmoded equipment and films. On the other hand, the use of radioactive materials as internal tracers, and a variety of new special radiographic procedures have not been included in this estimate and will eventually raise the average person's probable medical exposure.

In order to make the broad generalization necessary for a prospective nonoccupational exposure, those who choose to work with radiation are generally assumed exposed ten times as much as from the background sources previously mentioned. Technologists working in radiography, nuclear medicine, power reactors, radiation research, and various industrial applications readily expect some small increased risk in earning their livelihood, usually up to 500 millirem per year. This is the actual amount received by many radiation workers. The guides we shall discuss represent the significantly higher levels which may be accepted with good reason. Furthermore, nonworkers, members of the general public, are exposed to a lesser degree by these same activities, and separate guides are needed to evaluate their exposure.

GUIDES FOR EXPOSURES TO THE GENERAL PUBLIC

Two types of risks must be considered when evaluating exposures to large populations. The concept of the "General Public" as numerous, nonselected, of all ages and types, and probably unsuspecting and largely uninformed is both vague and suggestive of a high degree of liability. Therefore, the likelihood of one-time high exposure and levels of long-term low exposure are both severely restricted to nearly the level of natural, inescapable sources so as not to significantly increase exposure at all. The first kind of risk is the possibility that an increased rate of radiation induced disease may be generated, though the danger to any one individual is slight. These are the so called somatic effects risks for which a guide of a 170 millirem per person per year is generally used. The second kind of risk is to future generations, since radiation exposure to the gonads of the same group may alter the genes they pass on to their children.

Nearly all such mutations, though extremely rare, are harmful. The same number is used as a guide, 170 millirem per year; indeed, it is probably the same radiation source that is reaching the rest of the body.

In order to evaluate this genetic risk a number called the genetically significant dose or GSD, is computed to allow for the number of people exposed, as well as the level to which each person is exposed. Consider the radiation workers, of about 100,000 in number, who were occupationally exposed in 1967. Their significance in computing genetic damage is lost when included among the two hundred million people living in the United States that same year, but not receiving gonadal radiation from this source.

The GSD from any exposure to a large number of people is simply defined as that exposure which would be equivalent if delivered to everyone in the population instead of only to some. That is to say, if a specific dose is given to everyone in the U.S., that part which reached the gonads would be the GSD. Some smaller number would have to be applied to the GSD if in fact only a few of us received the same dose. Calculating the proper number is difficult, open to many sources of error and the details are certainly beyond this text. We need only to observe the guides which are designed to keep the GSD low.

The total nonoccupational exposure from all sources, to any large number of people, is to be kept below 500 millirem per person per year.

The total manmade exposure contributing to genetic effects is less than 10 percent of the GSD delivered today. This is the sum of radiation coming from our T.V. sets, luminous dials on our watches, luminous signs, a wide

variety of industrial equipment using radiation, the lingering fallout of atmospheric nuclear weapons testing and other manmade sources. Nuclear power plants contribute less than 4 percent of the GSD we receive from natural sources.

CONTROL OF RADIATION

Radiation exposures are maintained below guidelines by two means. The access to areas where radiation is used, radioactive materials are stored, and where levels of radiation above natural background are found, is generally restricted; only those having reason to be there are allowed to stay in such areas. Generally, personnel monitoring is done, for example, by requiring film badges to be worn so that any exposure in the restricted area is known. In many cases, even areas presenting only a risk of radiation exposure are closed to all unauthorized personnel, not wearing appropriate detection devices. The records thus obtained show the actual exposure workers received in performance of their duties.

The second control is directed towards the techniques, equipment, and skill used by radiation workers themselves. The philosophy is not one of setting some permissible safe levels, but rather one of keeping the exposure from each job at a minimum. The application of this "as low as practicable" or ALAP philosophy presents the need to consider the cost of exposure reducing methods. There may be additional equipment, more costly procedures, that would reduce the smallest exposures even more. When is radiation control sufficient in practicable terms? One effort to answer this question for the design of power generating reactors is stated in the Code of Federal Regulations, 10 CFR 50, Appendix I. The control of reactor effluent, at a cost of $1,000 or less for each rem per person per year in reduction of exposure, is required by law.

This precedent could be applied to other cases as an example of "as low as reasonably applicable" or ALARA guidelines. We sometimes find that this leads to numbers which may differ from guides imposed by the more restrictive policy of ERDA and its contractors following the ALAP philosophy.

OCCUPATIONAL EXPOSURE FOR THE FERTILE FEMALE

Special consideration must be given employed women of childbearing age in planning radiation control. Occupational exposure guides for fertile females must take into consideration the fact that the human fetus is the most sensitive stage of life for ionizing radiation. Furthermore, the early stages of pregnancy may be unrecognized, but the radiosensitivity appears highest. The guide for this case is stated in NCRP No. 39, paragraph 240. The objective, in brief, is to ensure that less than 0.5 rems will be delivered to the fetus during any pregnancy, even if unsuspected at first.

Employment of fertile females should be restricted to situations where slow, uniform accumulation of exposures is less than 2 or 3 rems per year. It is not clear what action may be taken if a young woman, though properly advised, chooses to work in the same higher risk environment as a male radiation worker is permitted.

CRITICAL ORGAN CONCEPT

Other guides are stated in terms of exposure to a specific part of the body or internal organ. Controlled radiation exposure is often to a very limited body area. For example, radiation therapy to a tumor is delivered as carefully as possible to the diseased tissue only, although surrounding

areas may be heavily exposed, and all parts of the body receive some radiation in the process. Many radioactive materials, if ingested, do not spread throughout the body, but concentrate in one or two special organs or tissues. For example, most iodine in the body ends up in the thyroid gland which concentrates both natural and radioactive iodine avidly. Therefore, guides are usually written not only in terms of total body exposure, but in terms of dose to the so called critical organ, usually the most highly irradiated part of the body.

The guides for external radiation are summarized in several publications. Table 6, page 106 of NCRP No. 39 gives us the following: to the skin of the body, 15 rems in one year; to the hands, 75 rems, no more than 25 to be received in any one quarter. To the forearms, 30 rems a year, and 10 per quarter. All other organs to be exposed less than 15 rems a year and 5 per quarter. Other guides previously mentioned are tabulated here as well. Virtually no one can draw on the old allowed exposure bank of (age - 18) X 5 rems with total body exposure and exposure of the lens of the eye restricted to 5 rems per year.

EXPOSURE GUIDE TERMINOLOGY

The basis for radiation protection guides for combined internal and external hazard is the traditional maximum permissable dose rate of 0.25 mR per hour. Note that this exposure rate, if it were multiplied by the approximately 2,000 working hours in a year, would total 500 mR. Special terminology is introduced in an effort to convert this measure of exposure to more readily measurable quantities or environmental standards.

First of all, the instruments designed to monitor exposure levels essentially count only a small fraction of rays emitted by a given source. While the source may be specified in the number disintegrations occuring in a given time, the efficiency of the detector determines the counts, if any, recorded. Supposing the activity can be detected under real conditions as actual counts above background radiation, some effort may yet be needed to define the minimum detectable levels in actual decays. Concentration guides are published for a large number of radionuclides. In particular, the guide concentrations of these materials in the body are listed as maximum permissible body burdens, or MPBB, in the National Bureau of Standards Handbook No. 69. This is the same information contained in NCRP No. 22, as revised in 1963.

Such body concentrations may be assumed to arise from activity concentrations found in the air and water supplies. For the corresponding maximum concentrations in air and water, one may refer to ERDA Manual Chapter 0524, titled "Standards for Radiation Protection". Other guides for ERDA and its contractors are summarized here as well. Further directives regarding surface contamination levels based on these air and water guides have been issued, though property contaminated to any detectable level is generally not released to the public anyway. Permissible doses and permissible concentrations are now used as guides, not as safe, permitted levels.

REGULATORY AGENCIES

Radiation is controlled by accepted practice in accordance with guides published from time to time by several authoritative agencies. Note that the use of radiation is strictly regulated by law. The regulatory agencies

responsible for legal requirements are innumerable, since radiation hazards are the concern of local fire departments, state health departments, professional organizations, and many others. The Nuclear Regulatory Commission (NRC) is the main federal structure controlling and licensing users of radiation. Many states provide their own control in agreement with NRC, such that the local authority for federal control will be the state atomic energy commission or state AEC. The Environmental Protection Agency, (EPA) is responsible for the code of law, which includes 10 CFR 20. This is the law governing the use of ionizing radiation, and does require much of the limitations implied in the guides. Primary sources for the guides themselves are the National Council on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Protection (ICRP). Generally in agreement, these organizations provide updated data and philosophy for accepted practice. When in doubt, the latest publications of both agencies should be consulted.

SECTION 10

DOSIMETRY

The primary function of a dosimetry program is measuring and documenting internal and external radiation dose received by individuals.

DETERMINATION OF EXPOSURE

Gamma exposures are usually determined through use of film packets (Figure 1), pocket ionization chambers and thermoluminescent dosimeters (TLD's). Self-reading pocket dosimeters (Figure 2) are worn by personnel when an indication of the degree of exposure is required immediately for exposure control purposes. When dose recording devices are inadvertently lost, damaged or are suspected of being exposed while not being worn, investigations are conducted and individual exposures are assigned on the bases of available exposure information from exposure rate measurement, pocket dosimeters or exposures recorded for persons in the same work area.

Beta exposures can be evaluated through the use of TLD's or film badge covered with various energy discriminating filters used to determine the energies of the incident radiation. The gamma exposure densities are subtracted from the beta plus gamma exposure densities to calculate the beta dose.

Neutron film packets are issued to persons who are working in the vicinity of nuclear reactors or neutron sources, and are used to determine fast neutron dose. Thermal neutron pocket chambers are issued to provide information for thermal neutron doses. Those personnel who work in areas of possible criticality accidents are issued criticality dosimeters which contain elements that are either activated or fissioned by neutrons of

different energies. Knowledge of neutron energies allows more accurate dose evaluation.

Radiation dose caused by internal deposition of radionuclides can be determined through biological analysis and/or by whole body counting techniques. Depending upon the radioactive material present, the dose may be delivered to one or more critical organs or to the whole body as a critical organ.

It is necessary to maintain records of measured radiation doses both for exposure control and legal purposes. If large exposures are being received, daily reporting is advisable to avoid exceeding maximum permissible exposure guides. Records must be maintained in a legal manner to comply with DOE regulations. Electronic data processing reports are used at most large installations to allow rapid reporting of large numbers of persons. Tight control methods must be used to assure that errors do not occur in the reports.

The limitations and accuracy of dosimetric procedures must be understood before the principles of personnel dosimetry can be applied reasonably and practically. Whole body gamma, beta and neutron exposures are measured with a very small film area compared to the area of the whole body. Variations in film emulsion densities, caused in manufacture or as a result of environmental conditions, may contribute to inaccuracies in film dosimetry. TLD's may become over sensitive, may be affected by triobolumenescence and cannot be reevaluated.

The Standard Man is used to establish permissible internal disposition guides but masses of the whole body and critical organs necessarily vary with each individual. In addition, excretion rates vary per individual and with time.

In emergency situations, commercial dosimetric devices may not be available. Dose estimates for individuals and/or the population may have to be made from exposure measurements such as rate meter readings and environmental samples.

FILM DOSIMETERS

The film badge packet is used to determine external radiation exposures. The developed film is both a measuring device and a permanent legal record. The film packet consists of one or more dosimetry films similar to dental x-ray film (Figure 3). The type or number of films used is dependent upon the measurement range desired. Gamma photons react with a filtering material to produce secondary electrons which affect the film emulsion just as light photons cause changes in the film emulsion. The filter, or the filtering material, is selected and used in the particular quantity necessary to assure uniform film emulsion exposure response over the usual wide gamma energy range encountered.

Calibration of gamma film packets is performed by exposing representative film from each manufactured emulsion batch to known amounts of radiation from a calibrated gamma radiation source. Films which are not exposed to the radiation of interest (control films) should be included in the calibration procedure. After development under controlled conditions, the

density of the control film is set at zero on a densitometer. Then, densities of the exposed film are measured in net optical density (NOD) units. Known radiation exposure versus NOD is plotted on a calibration graph for each manufactured batch of film. These curves are used to determine radiation exposures received by personnel wearing film from the same batch.

Processing of film includes developing, rinsing, fixing, washing and drying. Detailed procedures vary with the type of solutions and film used but specific procedures must be controlled within close limits to assure accurate film densities. Both control film and exposed film standards are processed with each group of personnel film to assure that background radiation densities (base fog) and calibration standard densities are correct after the film processing procedure.

Films exhibiting unusual densities are carefully examined to assure that the indicated exposures are valid and are not caused by such things as heat, light, moisture, and pressure damages. If a particular film exhibits environmental effects, an investigation must be performed which allows the individual to be assigned an exposure from other information such as dose rates in the exposure area, exposures received by accompanying personnel or exposures received by personnel doing similiar work. In all cases, it is essential that the film be easily identified with the individual. Therefore, a positive identification system must be established which may vary among different agencies.

Beta exposures usually are determined with the same film used for gamma exposure. Since beta radiation will not penetrate appreciable thicknesses of filtering material, it is necessary that the area surrounding the beta

detection area of the film not be covered with thick or dense material. The density contributed by any gamma exposure, as determined by various beta-gamma filtering methods, must be subtracted from the beta plus gamma "open window" density to determine beta exposure. Calibration for beta exposure densities is performed similarly to gamma exposure calibration except that the calibration is simplified by the more uniform beta density and dose response to a wide spectrum of beta energies.

Measurements of relatively small neutron exposures are complicated because neutron reactions vary with energy. Elastic collision of a fast neutron with a hydrogen atom in special film emulsion causes a proton recoil ionization track which can be observed microscopically. Films are exposed to known amounts of fast neutrons from a calibrated source and the resulting film standards are examined microscopically to determine tracks per unit area per unit dose (Figure 4). Care and practice must be exercised by film readers to assure accuracy of dose determination because film imperfections may easily be confused with tracks. Also, these special film emulsions when exposed to other radiations may exhibit sufficient density to obscure proton recoil tracks. It has been found advisable to shield the film with copper and lead to decrease film densities caused by other radiations in order to increase film efficiency for fast neutron radiation detection. The special emulsions used in neutron monitoring film depend only on highly hydrogenous materials surrounding the film to produce tracks from photons released to secondary radiation.

Some installations measure thermal neutron exposures by using cadmium filters over gamma film. The high cross section for a thermal neutron-gamma reaction

in cadmium results in gamma density which is a measure of the incident thermal neutron radiation. Other installations also use thermal neutron pocket chambers. In this case, exposure assignments must be documented. The measurement of intermediate neutron exposures with personnel monitoring devices is not sufficiently advanced at this time to be comparable to the accuracy of measuring other radiation exposures. Calculated intermediate neutron exposure rates can be used to estimate personnel exposures and such exposure estimates must be documented.

CRITICALITY DOSIMETERS

Methods for measuring very large radiation exposures must be provided in areas of possible criticality accidents. Of primary importance is the determination of the neutron energy spectrum which existed during a criticality accident. This usually is accomplished by using several different elements which have high cross sections for neutron capture at different neutron energies. Measurement of the activation radiations caused in each element allows estimation of the neutron energy spectrum and the approximate amount of neutron exposure. Common elements used in such criticality dosimeters, which may be worn by personnel or placed throughout possible criticality areas are gold, sulphur, copper, silver, and indium (Figure 5). In addition some criticality dosimeters utilize the fission principle by including fissile materials. Such devices can be rather bulky and are not worn by personnel but are placed throughout possible criticality accident areas.

The chemical elements in the bodies of personnel exposed to large amounts of neutron radiation may be used to estimate exposure by neutron activation analysis. For example, the blood contains large amounts of the stable

isotope sodium-23. Exposure to large amounts of neutron radiation causes formation of sodium-24 which is a gamma emitter. Measurement of sodium-24 gamma and the known sodium-23 content of the blood, allows estimation of neutron exposure after a criticality accident. Other activated elements in the body or on the person of the exposed individual may be used in the same manner. For example, phosphorous-32 in the hair and metallic buttons, belt buckles, watches, rings, and pocket change all can be examined for activation.

High gamma radiation doses could result from a criticality accident and might be above the range of gamma film measurement limits. Therefore, it is advisable to include high range gamma dosimetric devices for personnel working in possible criticality areas. Glass rod dosimetry is used extensively for this purpose. Changes in orbital electron energies caused by ionization in the glass rods can be measured as fluorescent emission under ultraviolet light at some time after exposure.

THERMOLUMINESCENT DOSIMETERS (TLD)

Recent developments in solid state physics have resulted in the increasing use of solid-state devices such as thermoluminescent dosimeters for dose estimation. Such dosimeters usually include LiF, CaF_2, $Li_2B_4O_7$, $CaSO_4$ or various other sulfates as the detector. Impurities such as manganese or dysprosium are added in minute amounts to these compounds as activators. Incident radiation causes electrons within the detector medium's atoms to be raised to higher energy levels. Upon heating to the proper temperature, these electrons are released to return to their original lower energy levels, releasing light photons in the process having an energy corresponding to the energy difference of the electrons as they fall from higher energy levels to

lower ones. The light photons can then be measured using photomultiplier tube techniques and quantitated. The number of light photons released upon heating is proportional to the amount of the incident radiation.

The most widely used thermoluminescent material is lithium fluoride (LiF). This material may be used in powder form or in extruded shapes or it may be impregnated in silicone or teflon base material. Thermoluminescent dosimeters can be used for detection of gamma, beta, and slow neutrons. These dosimeters have advantages over film dosimeters since they are relatively insensitive to environmental effects such as heat, light damage, and moisture. In addition, the usable range of exposure for TLD's extends into the kilo-roentgen region. As previously mentioned, TLD's can become over sensitive, may be affected by jarring, give false readings if discolored or dirty. They cannot be reevaluated once read.

SELF-READING POCKET DOSIMETERS

A self-reading pocket dosimeter consists of (1) a small air-filled chamber in which a quartz fiber electrometer is suspended; (2) a small microscope; and (3) a graduated scale across which the shadow of the quartz fiber moves to indicate the applied dose.

The design and operation of a self-reading dosimeter (Figure 6) utilizes the principle of discharging a pair of oppositely charged surfaces when the air between them is exposed to ionizing radiation. The electric charge required to attract the ionized gas particles is impressed on the electrometer and the chamber wall by means of a suitable charging unit. Ionizing radiation penetrating the chamber forms positively and negatively charged gas particles. These charged particles are attracted to the oppositely charged surface, i.e., the negative particles to the electrometer and the

positive particles to the chamber wall. The migration of the negative particles to the electrometer permitting the fiber to move closer to the frame which in turn causes the shadow of the fiber to move across the calibrated scale.

Self-reading pocket dosimeters are available in many ranges of gamma exposures from 0-200 mR to 0-1000 R. The sensitivity of the instrument is determined at the time of manufacture by the selection of the electrical condenser incorporated in the unit. Appropriate scale markings are provided with each dose range.

The dosimeter charger (Figure 7) is a small portable battery operated power supply designed to impress a DC voltage on the charging electrode of a dosimeter. In use, the dosimeter is inserted into the charging well and pressed down firmly. Pressing the dosimeter into the well serves two purposes: one, it actuates a switch that turns on a bulb so the fiber of the electrometer can be seen and, secondly, it closes the charging switch in the end of the dosimeter so that an electrical connection is made between the charging circuit and the electrode.

While holding the dosimeter firmly in the well, an adjusting knob (potentiometer) is rotated until the hairline is on zero. Frequently a capacitance effect causes the hairline to shift slightly, when releasing the contact with the charging well. This necessitates several charging attempts, setting the hairline slightly above or below zero to accomplish a zero setting when the dosimeter is removed from the charging well. However, it is not necessary to have an exactly zeroed setting since the exposure obtained can be determined by subtracting the initial reading from the final reading.

Self-reading dosimeters should be worn on the upper front part of the body usually in a shirt pocket with as little shielding material as possible between the dosimeter and the source of radiation. Generally, two dosimeters are worn at the same time - one of higher range than the other. This practice serves two purposes: (1) each dosimeter is a check against the other and (2) by wearing two dosimeters of different range the total range covered is increased. Self-reading dosimeters are quite rugged and durable; however, they are designed to be worn on a person's clothing and should not be subjected to severe shock; the wearer should immediately read the recorded dose of both dosimeters to determine if one reads significantly higher than the other.

The dosimeter is insensitive to beta and neutron radiation. Therefore, total dose estimates must consider not only the dosimeter measurements but also measurements taken with portable instruments which may include lower energy gamma, beta, and neutron radiation as well as dose reports from the film badges.

2.4.6 EXPOSURE CONTROL

Internal and external whole-body exposure control is more important than measurement of actual exposure after the fact. Monitoring of radiation exposure areas with portable dose rate or remote instrumentation allows prediction of exposures that will be received by personnel working in the areas. Self-reading pocket dosimeters should be worn by personnel who expect to receive exposures. In this manner, accumulated exposures can be obtained while they are being received, and personnel can leave exposure areas when they approach an established exposure limit.

However, since gamma film packets are considered as a legal exposure record, it is necessary that results of film processing be transmitted to the control location of an exposure area as rapidly as possible when exposures are of a magnitude that differences between dose estimations and film dosimetry could cause personnel to exceed established exposure guides.

Personnel dosimetry is valuable as an exposure control mechanism and has an equally valuable function in the measurement and documentation of exposures which already have been received by personnel. The accuracy of dosimetric measurements must be understood and considered in establishing exposure limits in controlled areas to assure that regulatory guides will not be exceeded. Dosimetry is an aid to exposure control, but it is secondary to sound exposure control measures.

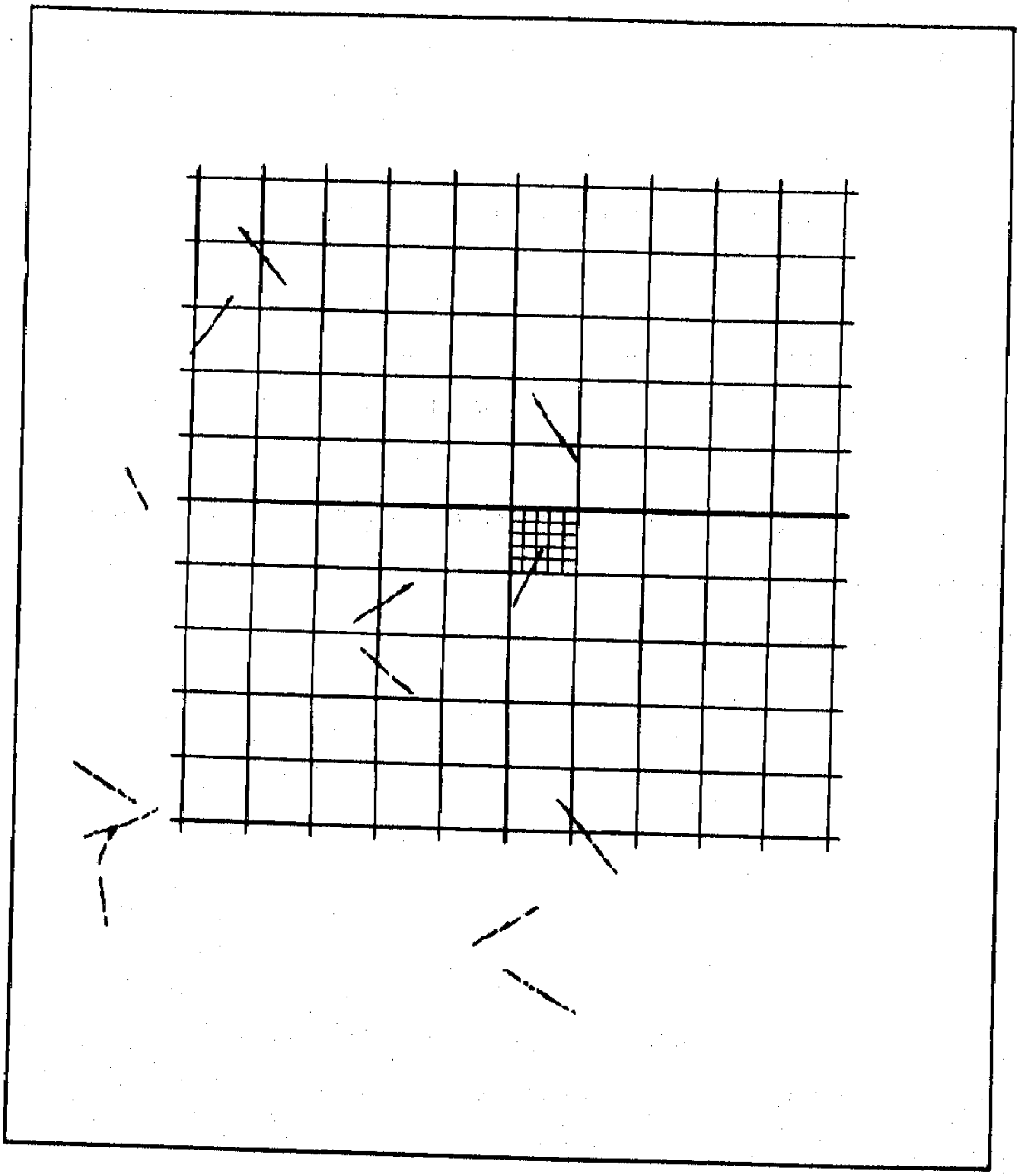


Figure 4. Neutron Tracks

SECTION 11

INTERNAL DOSIMETRY AND BIOASSAY

BACKGROUND

Internal irradiation results when the body is contaminated, either internally or externally, with a radioisotope. Accordingly, internal radiation protection is concerned with preventing or minimizing the deposition of radioactive substances on or in personnel. This is accomplished by a program designed to keep the contamination of the environment within acceptable limits, and at levels as low as practicable. The point of keeping the environmental levels as low as practicable is especially important in the context of internal radiation protection.

External radiation exposure is due to radiation originating in sources outside the body. There is no physical contact with the radiation source, and the exposure ceases when one leaves the radiation area or the source is removed. Since external radiation may be measured with relative ease and accuracy, the potential or actual hazard may be estimated with a good deal of confidence.

In the case of contamination, on the other hand, the radioactive material is deposited on or within the body. As a consequence, the contaminated person continues to suffer irradiation even after he leaves the area where he became contaminated. Furthermore, radioisotopes within the body may become systemically fixed. Their elimination then can be hastened, in those cases where possible, only with relative difficulty. Biological turnover rates, which may exhibit a marked variability, then become significant in determining the radiation absorbed dose from the internally

deposited isotopes. For these reasons, it is relatively difficult to access the hazard from internal emitters, and great emphasis is therefore placed on the prevention of contamination of personnel with radioactive material.

For protection against external radiation, the recommended maximum exposure limits are biologically meaningful and directly applicable, since it is a simple matter to determine the rad dose due to exposures for any given time in a radiation field. For protection against internal radiation due to inhaled or ingested radioactive materials, two different criteria are used, depending on the type of isotope under consideration. For bone-seeking radioisotopes, such as ^{90}Sr, ^{227}Ac, ^{232}Th, ^{231}Pa, ^{237}Np, ^{239}Pu, etc., which emit alpha or beta radiation, the maximum permissible body burden is based on a comparison with ^{226}Ra and its daughters.

For all other radioisotopes the matter is, in principle, as clear-cut as in the case of external radiation. The amount of a radioisotope is computed which, if deposited in the body, will deliver a dose not greater than 100 mrem per week if the total body, or gonads, or hemopoietic system is the critical organ. (The critical organ is defined as that part of the body that is most susceptible to radiation damage under the specific conditions considered.) For other body organs, the dose should not be greater than 300 mrem per week.

Having determined this quantity of radioisotope, which is called the maximum permissible body burden (MPBB), then, if biological information regarding the metabolism of the radioisotope is known, it is possible to compute concentrations of the isotope in air and water which would result

in the accumulation in the body after continuous exposure of no more than the maximum permissible body burden. Maximum allowable concentrations for all known radioisotopes, to which lifetime exposure is assumed, have been calculated and published in a report by the International Commission of Radiological Protection (ICRP). Included in this report are the detailed methods of calculation, together with the biological and physical factors necessary for the calculations. It is important to note that a short term or accidental exposure to environmental concentrations greater than the recommended maxima does not therefore necessarily mean that the person is overexposed.

RELATIVE HAZARD OF RADIATION TYPES

As earlier suggested, certain radioisotopes offer a greater internal hazard than others. Two of the factors that determine relative hazard are the nature of the radiation emitted by the radioisotopes, i.e., radiation types and the body's metabolic utilization of these elements.

In general, gamma emitters are not so severe an internal hazard as alpha and beta emitters. This is easily understood based on the mean path length of these types of radiation. Gammas, being very penetrating, could easily not interact (lose energy) within an organ or system of interest. Whereas even the most energetic beta particles can only travel several centimeters in tissue and alphas only a few millimeters. This infers that these types of emitters will lose essentially all of their energy in the body and this loss of energy means a tissue dose.

Since the body does not select elements based on their nuclear stability to be utilized in the metabolic processes, it is just as likely that a radioactive isotope is selected as a non-radioactive one if both are present in the same quantities. Where radioisotopes are used in metabolic processes and these sites are "sensitive" sites, great damage can be incurred by the organ or site. These sensitive sites are generally those blood-forming organs or reproductive system organs, especially when the effective lifetime of the radioisotope in the organ is long.

BIOASSAY SAMPLING

Bioassay sampling is the collection of generally routine biological excreta, such as urine, feces, and breath. In the broadest sense, bioassay samples also include nasal mucus, blood, gold fillings, and hair. Urine sampling is by far the most common type of bioassay sampling.

The main purposes of bioassay sampling and analysis are: (1) to evaluate the effectiveness of protective measures, (2) to indicate exposures too low for future concern, (3) for dosimetry of internally deposited radionuclides, (4) for research, and (5) for legal purposes.

Serious consideration must always be given as to the type of bioassay sample taken along with the method or routine of sampling in order for the data derived from the sample to be indicative of contamination in the critical organ or whole body. It is extremely important to have as much information about the chemical form of the containment as possible, such as whether or not the radioisotopes is soluble, insoluble, transportable or non-transportable in order to select the appropriate type of sample

to be taken for dose calculations. Also, particularly important in urine sampling is the collection of a representative sample. The best method, if continuous sampling is not possible, is the "24-hour" sample, i.e., all the urine collected that is excreted in a continuous 24-hour period. If this is not possible, then the "mock" 24-hour sample is desirable. This sample is the collection of the first voiding after awaking in the morning.

Bioassay sampling and analysis generally require a high capital cost, a relatively small analysis cost and little lost-work time by the person giving the sample.

WHOLE-BODY/CRITICAL ORGAN SCANNING

Whole-body or organ scanning is a much more sensitive type of analysis since in these cases the quantities of gamma-emitting radioisotopes actually in the whole body or organ are measured. Of course, this type of external scanning is only applicable to gamma-emitters. This in-vivo counting requires high capital cost, cheap analysis cost and a relatively large time cost in collecting data from sample (people).

Some types of scanners include: (1) large volume organic liquid detectors that totally surround the body filled with liquid organic scintillators, (2) body-scanning systems, such as shadow shields, with usually a large inorganic crystal detector, and (3) multi-crystal or multi-detector arrays in shielded rooms. Partial-body counters for specific purposes, such as, thyroid counters and wound monitors are usually made up of several types of small inorganic crystals. Lung counters are used to monitor the lung

for non-transportable inhaled materials, and are quite similar to whole-body counters. In medical health physics, brain scanners are used frequently.

In all applications, involving particularly whole-body counting, shielding is very important, as is usually a major item in the high capital cost in the setup of a system.

In some circumstances, whole-body counting could be psychologically upsetting to some people, due to the degree of confirement and isolation required by some systems. Some safeguards must be designed in each system to handle these human problems.

DOSE ESTIMATION

Before any internal dose can be assessed, some basic concepts of (1) the standard man, and (2) ingestion and inhalation model must be briefly described.

The standard man and standard man data are a compilation of data on various physical, chemical, physiological, and metabolic aspects of this "defined" man. These data indicate masses of the major organs of the body, including the whole-body chemical composition, rates of intake (food and water), and rates of elimination; define the areas inside specific organs; and define the density of all organs as that of water and the shapes of all organs as either spheres or cylinders for ease of calculations. These data can be found in the report of the ICRP and the Handbook of Radiological Health.

The ICRP has described a model that is quite widely used by health physicists for performing dose calculations. It establishes exchange rates between

various organs in the body and assumes that the rates elimination of radioisotopes from organs and the whole-body may be described as single or multi-component exponential function. This exponential elimination assumption is not the only possible one for bone-seekers. In this case a power function may also be used to best describe the elimination rates. In the case of body or organ scanners, the calculation of dose is straightforward based on the counts measured by the counter, length of count, geometry/efficiency factors and background. The results usually relate the quantity in the critical or whole-body as a percentage of the MPBB for that particular radioisotope.

Dose or body burden determination is not so simple from the analysis of bioassay samples. Two major factors must be considered (1) "in situ" radioactive decay of the isotopes and (2) biological elimination of the isotope. As mentioned earlier, in most instances, biological elimination follows first-order kinetics. In this case, the equation for the quantity of radioisotope within an organ at any time t after uptake of a quantity of Q_0 is given by $Q = (Q_0 e^{-\lambda_r t})(e^{-\lambda_b t})$ where λ_r is the radioactive decay constant, and λ_b is the biological elimination constant. The calculation of absorbed dose from internally deposited radioisotopes then follows directly from the definition of the rad. Dose due to total decay of initially deposited quantity Q_0 is determined by integrating the instantaneous dose rate with respect to time. The equation has the following form: $D = D_0 \int_0^t \exp[-(\lambda_r + \lambda_b)t]dt$, where D_0 is the dose rate at time $t = 0$, the instant when the quantity Q_0 of isotopes was taken up by the tissue.

There are inherently some unknowns in the dose calculation that limits the accuracy and reliability that can be attributed to the calculated dose. Two of these major factors are: (1) the lack of well known quantitative relationships between intake, uptake and elimination rates and (2) the general uncertainty of the time since intake.

After the dose is estimated from the time of uptake to sampling, the problem then becomes only a matter of determining the "dose commitment" from that quantity of internal contaminant. The dose commitment is defined as the total dose that the organ or body will receive from a quantity of radioisotope while it is in the body or within fifty years, whichever is shorter.

RADIOPROTECTIVE PROPHYLACTICS AND TREATMENT

Knowledge of the radioactive environment or potential environment along with proper planning and procedures for the operation is the best insurance in protecting personnel from internal or external exposures. Of course, proper dress-out clothing and techniques, appropriate properly fitted respirators, good hot-line procedures and adequate instrumentation are all essential in assuring that internal depositions are minimized.

Once an internal deposition has occurred, reducing the quantity of the contaminant is possible in only a few cases. The elimination rates, therefore, are only affected by λ_r and λ_b.

In the case of a tritium exposure, the body water can be forced to turn over at almost twice the normal rate by forcing fluids. In the tritium

case, forcing is only effective when the individual is exposed acutely to rather low concentrations of T_2, HT, HTO T_2O or other organic tritiated hydrocarbons.

If radioiodine is a potential contaminant, administering a stable iodine tonic, usually in the form of potassium iodide during the first few hours following intake, will essentially block (saturate) the thyroid and a large fraction of the radioiodine intake will pass in the urine within a few hours. The uptake half-time is about 4.5 hours. Therefore, early action is desirable.

Contaminated wounds are handled under the direction of a physician. They can be excised, flushed with water or treated with strong chemical oxidizing agents in an effort to make the contaminants, soluble, and therefore removable by flushing with water.

Where the body, organ or wound is contaminated with large activities of lanthanides or transuranics, there are chelating and complying agents available that can be administered by physicians, if in their judgement the benefit is worth the risk. These compounds do have other side effects. The name of one of the controversial compounds is calcium-trisodium diethylenetriaminepentaacetate (-DTPA).

Following an incident, immediate first aid may be needed of associated trauma or chemical injuries. Determination of the presence of surface contamination, and suitable decontamination procedures, if it is present, will obviously follow. Treatment, depending on the severity of the incident,

will utilize principally the following methods: (1) rest, (2) superior nursing care, (3) strict asepsis, (4) transfusions and antibiotics, (5) maintenance of proper fluid and electrolyte balance and (6) maintenance of nutrition.

SECTION 12

DETECTOR FUNDAMENTALS

Since radiation cannot be detected by any of the human senses, we must depend upon instruments to warn us of the presence of radioactivity. These instruments detect the effects produced by the interaction of radiation with some types of matter, and through the measurement of these effects can generate information as to the nature of the radiation present.

Interaction of radiation with matter results in ionization. Each time an ionizing event takes place an ion pair is formed which consists of a positively charged atom and a negative free electron.

In a radiation detector we collect the negative electrons freed during the ionization process. The usual rules of electrostatic attractions, that like charges repel and unlike charges attract, are applicable.

Basic Gas Filled Detector Circuit

Three things must be present in order that radiation may be detected and measured: (1) A sensitive volume where interaction can take place; (2) An electric field within the sensitive volume; (3) A type of visual or aural presentation so that information can be evaluated.

Figure 1 shows a basic detector circuit consisting of an ion chamber (sensitive volume), battery, and load resistor (difference of potential), capacitive coupling to amplifier (visual-aural presentation).

When a difference of potential exists across the sensitive volume and ionization occurs within it, the ions created will travel to the terminal

or electrode having an opposite charge. Collection of these charged particles on the electrodes will produce a current flow which can be measured in an external circuit.

The most common type radiation detectors have two electrodes in a coaxial configuration as shown in Figure 2. The center electrode is called the anode, positive, and the outer electrode is called the cathode, negative. The negative free electrons which occur through ionization are collected on the positive anode creating a current flow through the load resistor of the circuit. The positive half of the ion pairs are neutralized at the outer electrode or cathode.

Pulse Height Versus Applied Voltage

Figure 3 shows a typical response curve for ionization detectors. The curve is divided into several regions. The "ion chamber region" is composed of two subregions; the "recombination subregion" and the "saturation subregion." When a very low voltage is applied across the detector, ion pairs will be formed, but due to the low potential difference some "recombination" of electrons and positive ions will occur. This recombination process will continue in a decreasing manner until sufficient voltage is applied across the detector to prevent any further "recombinations" and the saturation subregion is reached. Through this region electrons are collected at a rate of one for each primary ionization event which takes place within the "sensitive volume" of the detector.

As the detector voltage is increased beyond the "saturation subregion," the "proportional region" or region III of the pulse height curve is encountered and pulse height begins to increase due to "secondary

ionization." This process creates an "avalanche effect" and results from electrons, which are freed during primary ionization events, gaining enough velocity as they move through the potential difference across the detector to produce other ionizing events. Thus, more electrons become available for collection than were originally created by primary ionization events. This increase (buildup) of electrons increases the size of the output pulse from the detector and is called "gas amplification." The gas amplification factor (a) is defined as:

$$A = \frac{\text{Number of electrons collected}}{\text{Number of primary ionizations}}$$

Increase in pulse height due to gas amplification remains linear through the "proportional region" with increased detector voltage.

Detector tubes and chambers are designed so that the diameter of the central wire (anode) is very small. This results in a strengthening of the electric field intensity near the central wire which aids the avalanche effect. It has been determined that a particular instrument using .001 inch central wire has most of the avalanche effect occurring within .005 inch of the wire. As the detector voltage is increased the avalanche electrons begin to obtain enough energy to penetrate outer electron shells and excite inner shell electrons. When an inner shell electron is excited so that it can escape from the atom, an outer shell electron will fall from its orbit to fill the vacancy. This results in the emission of a photon (usually ultraviolet) which, in turn, causes ionization by interaction with other atoms and creates a new avalanche effect. When inner shell electrons are excited they also yield photons upon de-excitation.

The limited proportional region is encountered as voltage is further increased. Ionization of atoms and excitation of electrons in this region cause a rapid irregular increase in the pulse height which is no longer linear. For this reason, instruments are not designed to function in the limited proportional region.

The Geiger-Mueller (GM) Region is encountered above the limited proportional region. The amplification in this region becomes very high and each ionization event occurring within the sensitive volume will produce enough photons to completely ionize the detector. All output pulses will look the same regardless of the type of radiation entering the detector. Alpha, beta, and gamma all give the same indication in this region. If voltage is increased beyond the Geiger region, there will be a breakdown (arcing) in the detector and a continuous discharge results, essentially shorting out the electrodes.

Ionization Chambers

The pulse counting ion chamber (Figure 1) is normally only used to detect alpha particles. The indication given by this type instrument consists solely of pulse rate or events per unit of time. Operating voltage varies with detector geometry and sensing gas, although it is generally below 300 volts. Pulse width ranges from 10 to 50 microseconds as determined by the RC time constant of the detector circuit.

Since noise pulses of 10- to 20-microvolt amplitude are present in even high quality amplifiers, the pulse counting ionization chamber cannot be used to count particles of low specific ionization (beta and gamma). It

is useful for alpha particle detection and is used in special purpose applications for detecting protons and fission fragments. Since pulses formed by beta and gamma radiation are very low in amplitude, this chamber can be used to measure alpha in the presence of beta and gamma. Low to moderate voltages are feasible since the only functions of the electric field are to prevent recombinations and collect electrons. Voltages high enough to cause secondary ionization are not required for operation in the ionization region of the pulse height curve.

If we purposely make the detector load resistor very large (10^{10} to 10^{12} ohms), an entirely different type of detector operation results. The time constant of the detector circuit will now be on the order of seconds instead of a few microseconds and electrons collected on the anode will not have time to "leak off" through the load resistor between pulses. They will build up to a constant charge which is proportional to the number of ions produced per unit time.

The integrating ion chamber differs from the pulse counting ion chamber in that it measures intensity (dose rate) rather than individual pulses or ionization events.

Integrating ion chambers are quite suitable for portable survey instruments since their output voltage is proportional to dose rate, they utilize relatively low operating voltages, and they can be operated in radiation fields of high intensity.

Proportional Detectors

Gas amplification occurs in the proportional region giving a large pulse. This region is generally reserved for alpha detection. However, it is

possible to obtain beta sensitivity at the higher voltage portions of this region.

A proportional instrument (Figure 4) has a recovery time (pulse width) in the vicinity of 10^{-4} seconds. Typical operating voltages of chambers at atmospheric pressure range from 1300 to 2600 volts. The gas amplification factor in this region is between 10^2 and 10^4.

Detector voltage is plotted against meter readings (Figure 5) to select the appropriate operating level for specific instrument. To accomplish this, a calibrated radioactive source is placed under the instrument probe. The high voltage is increased by small increments, and readings at various voltages are recorded on graph paper which results in a characteristic curve when plotted out. Depending on the individual instrument used, there will be a small plateau on this curve that will vary from tens of volts to a few hundreds of volts in length. Detector operating voltage is then adjusted for approximately the middle of the plateau to compensate for variations in detector voltage or environmental changes which could result in significant changes in the operation of the instrument. In an area where a great deal of high energy beta may be encountered, the lower third portion of the plateau will be used to discriminate against beta readings. Changes in altitude (atmospheric pressure) may necessitate readjustment of the operating voltage on the plateau also.

<u>Geiger-Mueller Detectors</u>

In GM detectors (Figure 6) the voltage pulse height across the load resistor will be the same for any ionization event occurring within the detector

since each event produces complete ionization within the detector cavity. Therefore, there is no discrimination between types or energies of detected radiation.

The time required for an avalanche to go from initial ionization to final collection at the anode is about 10^{-7} seconds (Figure 7). A period of approximately 10^{-2} seconds is required for the positive ions to travel to the cathode and be neutralized. Since the electrons are collected much more rapidly, a positive ion "sheath" forms concentrically around the central electrode and moves to the outer wall after the electrons have been collected. Additional electrons will not be able to penetrate the positive ion sheath until the sheath is a certain distance from the anode. This distance is called the critical radius. The time it takes for the positive ion sheath to move to the critical radius is known as dead time (Figure 8). The time required for the positive ion sheath to move from the critical radius to the cathode wall is called recovery time (Figure 9).

Ionizing radiation will not be detected if it enters the probe during dead time. If radiation enters the probe during recovery time, it will be detected but the pulse produced will be of a smaller magnitude than normal. Therefore, if a GM detector is used in a very high radiation field, only one pulse would be recorded between successive dead times. In an intense radiation field the tube may become saturated and may not be able to recover at all, producing a zero or erroneous reading on the meter. Some instruments indicate zero when saturated and some will fluctuate around a number characteristic of the saturation of that particular instrument.

Neutralization of the positive ion sheath at the detector cathode induces a process known as "retriggering" which can be explained in the following manner. When the positive ions are neutralized, photons or x-rays are emitted as a part of the electron capture process. One or more of these photons may cause emission of a photoelectron from the cathode surface. When the photoelectron enters the sensitive volume of the detector, it acts in the same manner as a primary electron produced by radiation and will retrigger the detector, producing a false count.

Because of this retriggering process which occurs throughout the Geiger region, the detector will be useless unless some method to prevent retriggering is employed.

"Quenching" is the term applied to methods employed which prevent retriggering. It may be either internal or external.

Internal quenching is accomplished by filling the sensitive volume of the detector with a mixture of a noble gas (argon, neon, krypton, etc.) and a polyatomic (organic) gas, or a mixture of a noble gas and a halogen gas, i.e., fluorine, chlorine, bromine, iodine, etc.

Both of these mixtures lead essentially to the same process. As the positive ion sheath moves out to the cathode, an electron-transfer process from the polyatomic or halogen gas molecules to the ionized noble-gas molecules takes place.

The photons of energy created during the neutralization process will be absorbed by the strong ultraviolet absorption properties of the polyatomic

or halogen gas molecules. Noble gas ions will transfer their charge to the quenching gas molecules, which have a lower ionizing potential, and the resulting ions will collide with the cathode where they will dissociate. Any residual energy not absorbed in the dissociation process will be re-radiated as low-energy photons which are not energetic enough to eject a retriggering electron.

Instead of emitting a photon these gas molecules will consume energy by dissociating and any residual low energy photons will be incapable of producing a photoelectron.

Using a polyatomic gas such as alcohol, a concentration of ten percent by volume will provide satisfactory operation of a GM detector through a fairly wide range of voltages, However, the use of polyatomic gas quenching limits the counting life of the detector to from approximately 10^8 to 10^{12} counts. This is because over a period of time a portion of the polyatomic gas is used up (dissociated) permanently and the detector is no longer self-quenching and will retrigger.

Using a halogen gas, such as Cl_2 in place of the polyatomic gas will give the detector practically an unlimited lifetime. The chlorine molecules do not become permanently dissociated over a period of time, but will recombine to form useful Cl_2 molecules again. However, the halogen elements are very corrosive and will damage the interior metallic surfaces of a detector which can affect detector operation when damage reaches a certain point.

Because of these separate advantages and disadvantages, we find that in practice both polyatomic and halogen gases are used for internally or self-quenched GM detectors.

External quenching may also be used with the GM detector. In this method an external circuit is used to lower the voltage applied to the detector until after the positive ion sheath has been neutralized at the cathode. This essentially takes the detector out of the Geiger region for a short interval following each pulse or discharge and prevents retriggering. This method could be compared to a light bulb being turned "on" and "off." The detector might be "on" for 1 microsecond and "off" for 1 millisecond and will only detect radiation during the "on" portion of the cycle. It would be insensitive during the "off" time. The instrument would be calibrated to read as if it were detecting radiation continuously. The external method is seldom if ever used since it is quite more involved in the practical application.

Several conclusions may be drawn concerning Geiger-Mueller detectors based on their quenching, discharge phenomena, counting characteristics, etc.

1. The pulse amplitude is large for every detected event and requires little, if any, amplification. Thus, this detector requires very little instrumentation which makes it ideal for small survey instruments.
2. They are stable and usable over a wide range of detector-applied voltages.
3. Due to the dead time after each pulse or discharge, they have a limited counting rate in the order of 10^4 counts per second.
4. They cannot discriminate between types of energies of radiation since all output pulses are of the same shape and amplitude (except those during recovery time).
5. They must be quenched by some means to prevent retriggering after delivery of an initial pulse.

6. If they contain polyatomic gas for quenching purposes, they will have a finite lifetime on the order of 10^{10} counts.

Scintillation Detectors

Detectors previously considered have all been gas ionization types which are subject to certain limitations such as detector efficiency and maximum counting rate. The Geiger-Mueller detector, for example, is low in both of these areas, usually about one percent for gamma detection, and around 10^4 counts per second maximum counting rate.

A different type of detector, the scintillation detector, has been developed to overcome these limitations. It may be of either solid or liquid form, and consists of two elements, a fluorescent material and a photomultiplier tube. The fluorescent material fills the sensitive volume and interacts with incident radiation to emit photons of energy in the form of visible or ultraviolet light. Some, usually about half of these photons, impinge on the photo-cathode of the photo-multiplier tube and ejected photoelectrons are attracted to electrodes called dynodes within the tube and cause secondary emission which results in signal amplification.

Detector voltage applied to the photomultiplier tube is divided or "staggered" in an increasing sequence through the dynode string. The last electrode acts as a collector for the electrons and gives off an output signal which can be detected and measured.

Figure 10 illustrates the interaction of incident radiation with the phosphor or fluorescent material absorbing energy and emitting photons as visible or ultraviolet light. These light photons impinge on the photocathode of the photomultiplier tube.

The photocathode is made up of an oxidized alkali metal which has a very low work function. The work function of a surface is a measure of the amount of energy an electron must have to leave the surface. Since the photons impinging on the photocathode are in the 3 or 4 eV energy range, it is imperative that the work function at the surface of the photocathode be extremely low for proper operation.

The dynode surfaces have the same low work function characteristics as the photocathode. Figure 11 illustrates increased secondary electron emission as electrons progress from one dynode to the next and finally arrive at the collector.

Associated with each dynode is a secondary-emission yield factor which may be defined as the ratio of the number of electrons emitted to the number of electrons impinging on the surface. This factor is a function of inter-dynode voltage and varies over a wide range.

The gain of a photomultiplier tube is an extremely sensitive function of tube voltage. Typically, a one percent change in voltage will result in approximately a 10 percent change in gain. Because of this, a very stable, well-regulated voltage supply is required for satisfactory operation. Scintillators are primarily used in laboratories; however, by careful design, they can be used as portable survey units.

The most severe limitation of scintillation detectors is their noise output level usually expressed as "dark current." This results from two principle causes: ohmic leakage and thermionic emission. Of the two, thermionic

emission is the most critical and occurs at the low work function photocathode, even at room temperatures. Electrons emitted by this process will be attracted to the dynodes and cause secondary emission. Thermionic emission from the photocathode results in essentially the same amplitude output pulse as occurs from actual radiation interaction.

To negate the effects of noise or thermionic emission, it may be necessary to cool the photomultiplier tube or use it in a coincidence mode--two or more photomultiplier tubes and a single phosphor.

Interdynode voltages of 80 to 100 volts giving a secondary-emission yield factor of approximately four are usually chosen for photomultiplier tube operation. At higher voltages excessive high noise outputs result from ohmic leakage and thermionic emission, thus making higher operating voltages impractical.

A typical scintillation detector has a counting rate of 10^8 counts per second. This is high in comparison to other detectors previously mentioned.

Neutron Detectors

Neutrons are electrically neutral and do not cause ionization directly. Therefore, indirect methods must be employed in neutron detection.

Neutrons produce ionization through bombardment of other materials, often referred to as a target. This bombardment process causes ionization as the result of two general reactions: a nuclear reaction and a recoil reaction.

Revised: January 1978

The nuclear reaction, caused by a neutron entering the nucleus of an atom, results in the release of an alpha particle. The alpha particle then causes ionization which is detectable by conventional methods.

The recoil reaction occurs when a neutron collides with a light atom, i.e., hydrogen. In this case, the force of the collision causes a proton to recoil from the nucleus at high velocity and with considerable ionizing ability.

Detection methods may vary with respect to neutron energies. A different method or detector is used to detect slow neutrons than that used to detect fast neutrons. Slow neutrons are detected by nuclear reactions with boron-10 or with a material which has a high cross section for fission with low energy neutrons, i.e., ^{235}U.

The boron chamber, Figure 12, is the most commonly used neutron detector. It is normally a small cylinder containing boron trifluoride gas ($B^{10}F_3$) or it may contain boron-10 in solid form. In the latter case, the cylinder wall is lined with a thin layer (0.1 mm) of boron and the cylinder filled with a noble gas (argon, etc.) for interaction. This detector functions as a proportional counter to detect the alpha particle released due to nuclear reaction between the neutron and boron-10.

Another type of neutron detector is illustrated in Figure 13, and is called a fission chamber. Fission chambers are constructed similar to the boron chamber. For slow neutron detection, enriched ^{235}U is used to line the chamber wall since it will fission readily when bombarded by slow neutrons. This chamber is not used extensively because of the prohibitive

cost and limited supply of ^{235}U. Fission chambers are most often used for detecting fast neutrons. In this case, the chamber is lined with depleted ^{238}U which fissions with fast neutrons and is readily available.

Scintillation detectors are also used to detect neutrons. The energy of particular neutrons detected by this method is a function of the scintillation crystal used. The crystal is impregnated with a target material which gives off ionizing radiation when bombarded by neutrons. It may be of either solid or liquid form. Solid crystals are normally used to detect fast neutrons by recoil reaction. Liquid scintillators are used to detect slow neutrons by incorporating boron into the phosphor material to create nuclear reaction.

The slowing down of neutrons is called moderation. Materials used for this purpose are called moderators and are used to extend the capabilities of neutron detection instruments. Figure 14 illustrates a moderator surrounding a boron detector. This detector can detect both fast and slow neutrons.

Any material with a high density of hydrogen atoms is a good moderator for neutrons. Hydrogenous material has a large (n, p) cross section for fast neutrons. By surrounding a slow neutron chamber such as a boron chamber with water, paraffin, or polyethlane, it can also be used to detect fast neutrons. The moderator slows the fast neutrons and allows them to react with the boron-10 and produce an alpha particle.

It has been shown that the usefulness of a neutron chamber may be enhanced when surrounded by a moderator. If the prime interest is in detecting neutrons as such, use of the moderator will serve to increase detector efficiency and more neutrons will be detected. However, neutrons with differing energies require some means of discrimination if they are to be segregated. This is accomplished by surrounding the moderator with a material such as cadmium, which captures (stops) thermal and slow neutrons before they enter the chamber. Thus, by using a moderator and cadmium shield in conjunction with a bare boron tube, slow and fast neutrons can be detected.

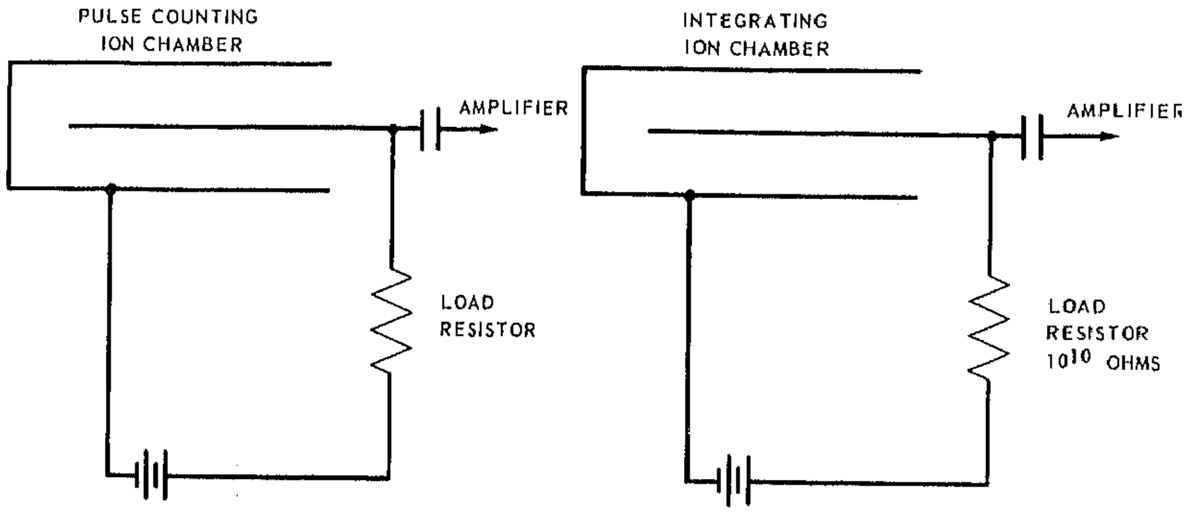


Figure 1 Ion Chambers-Integrating & Pulse Counting

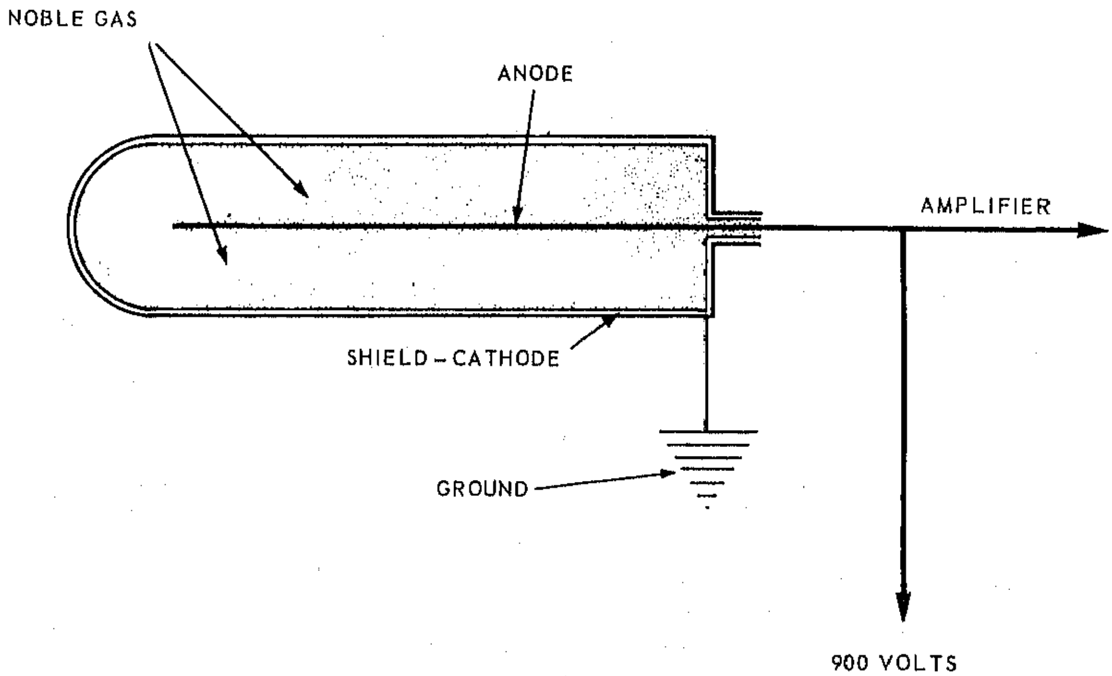


Figure 2 Radiation Detector - Ionization

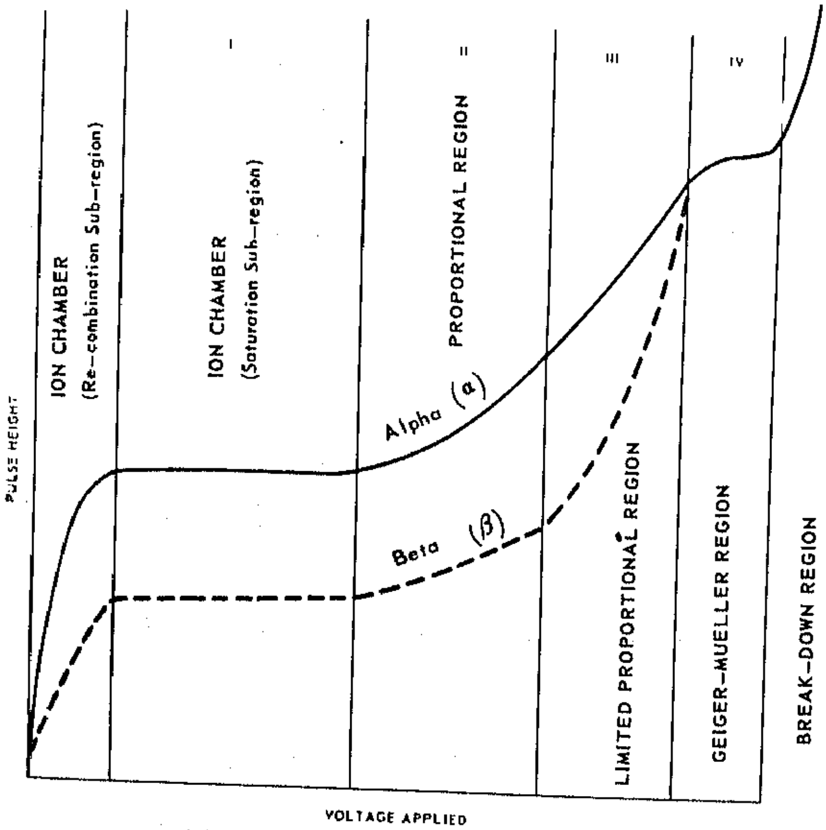


Figure 3 Ion Chamber Response Curve

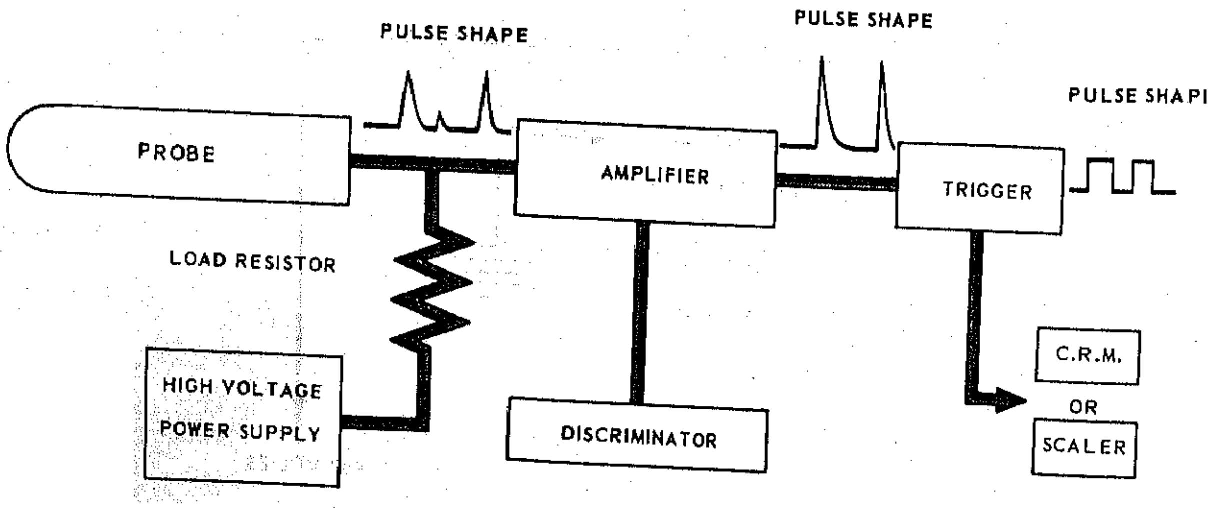


Figure 4 Typical Proportional Detector

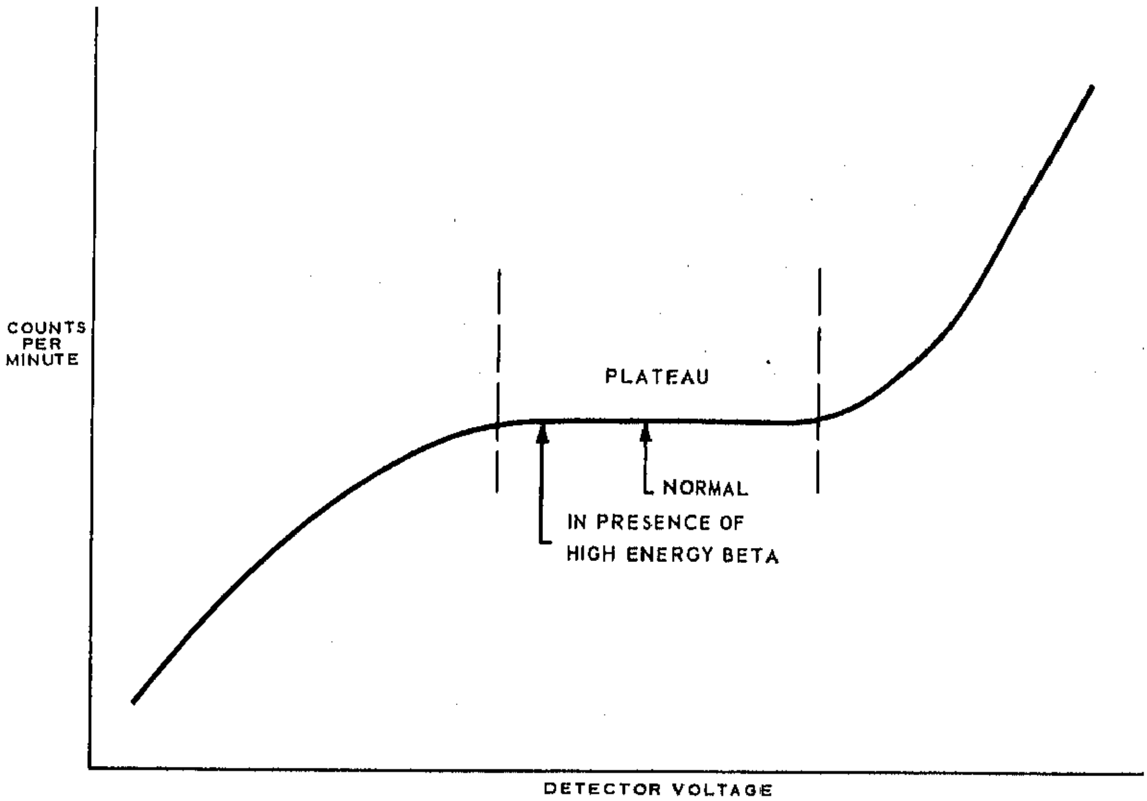


Figure 5 Proportional Detector Plateau

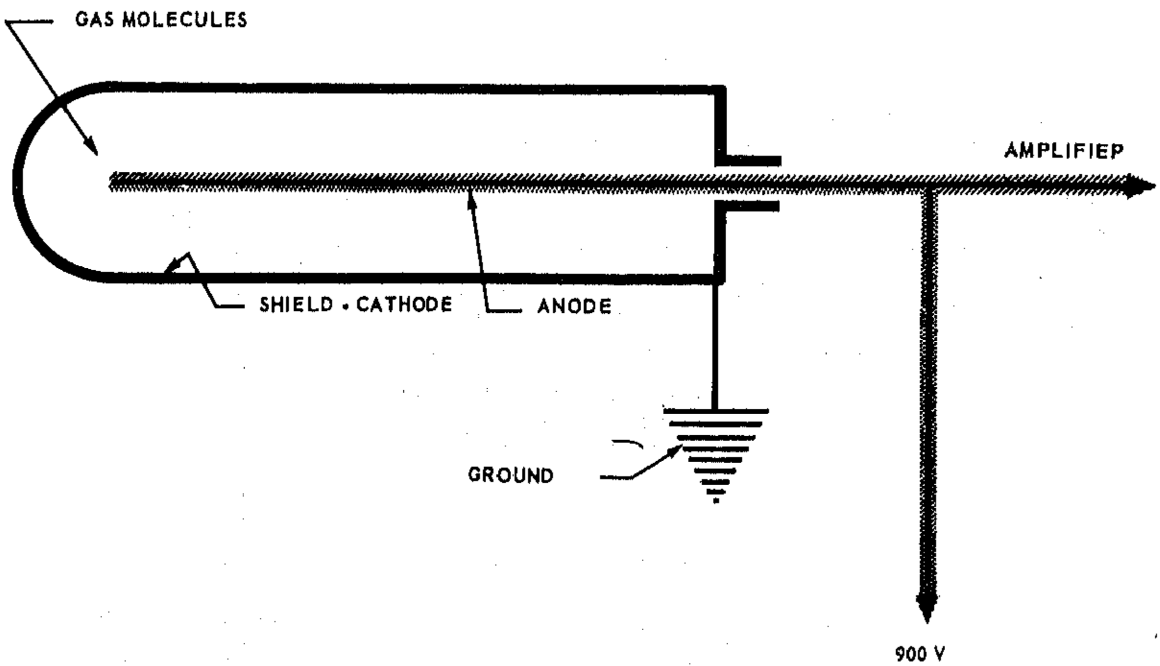


Figure 6 Geiger-Mueller Tube

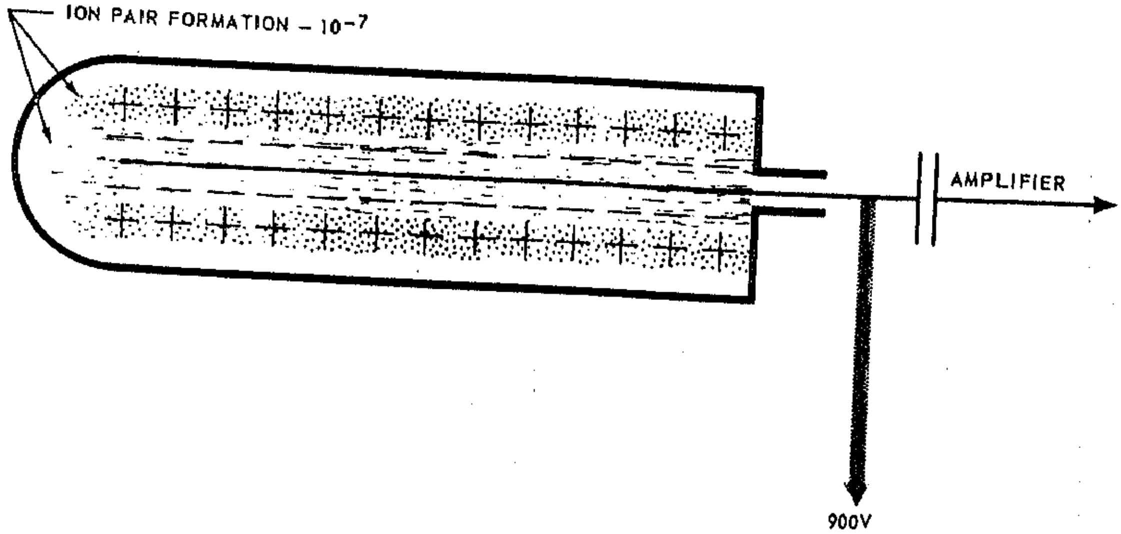


Figure 7 Ion Pair Formation

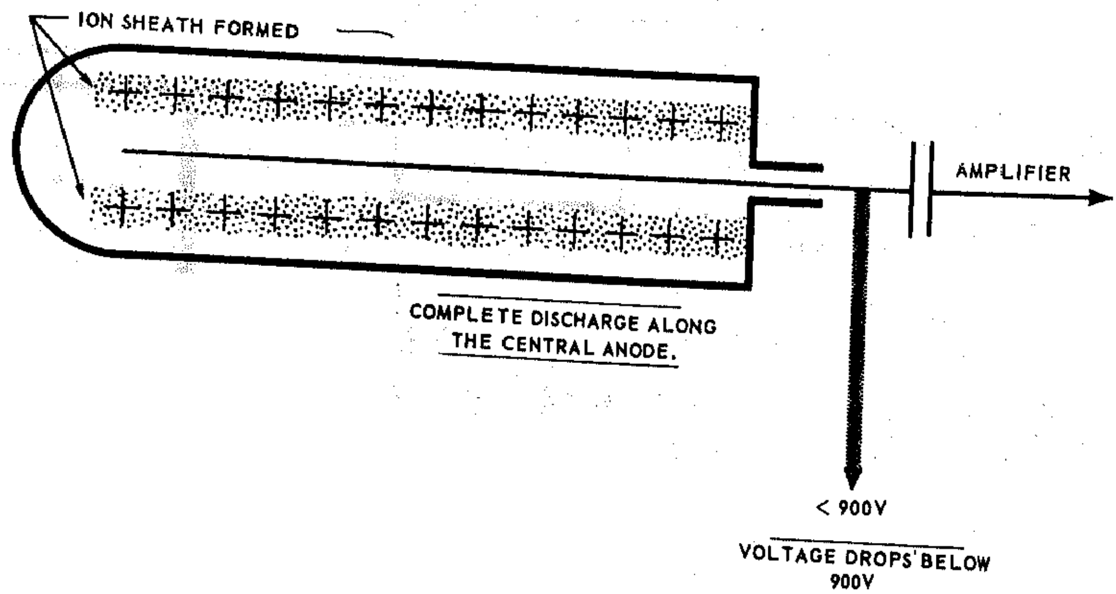


Figure 8 Dead Time

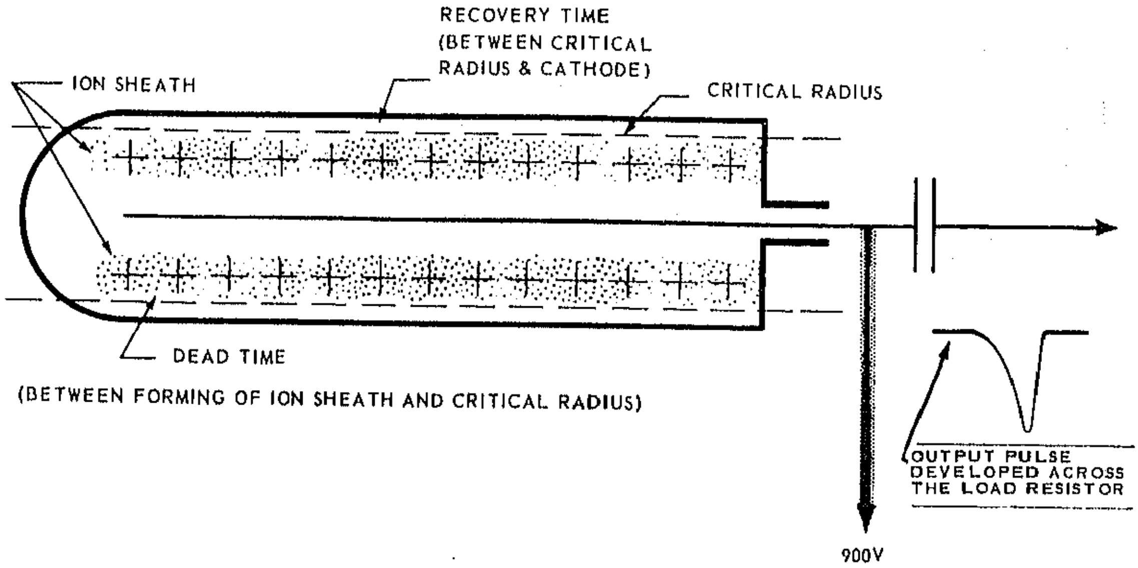


Figure 9 Recovery Time

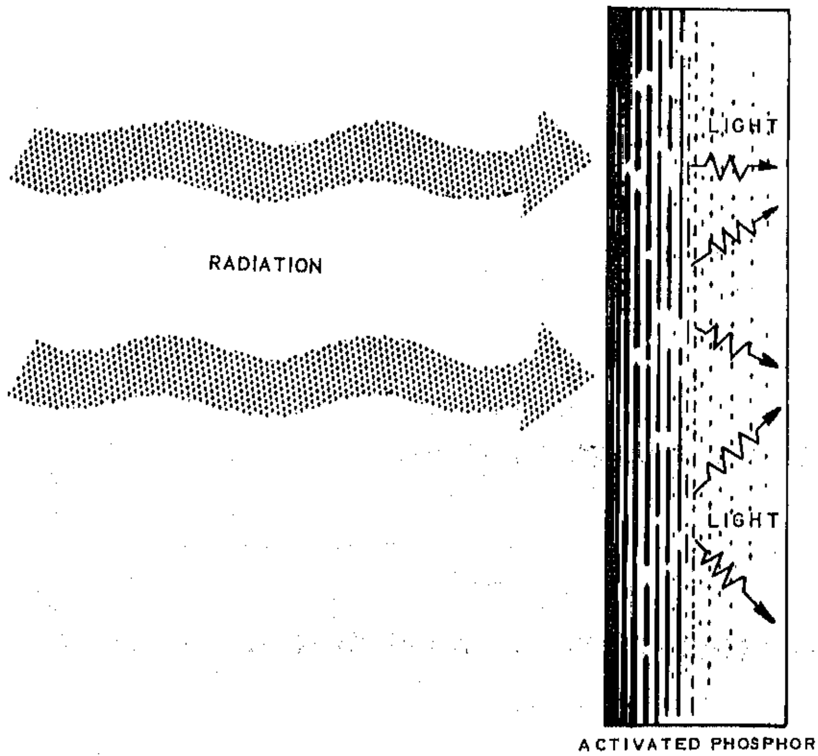


Figure 10 Scintillation Detectors

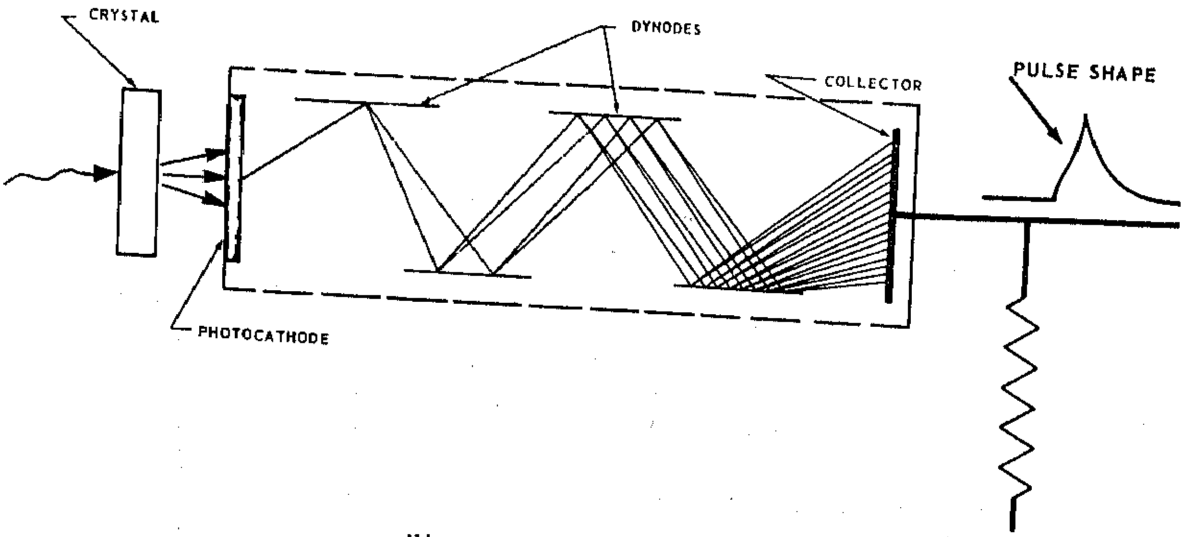
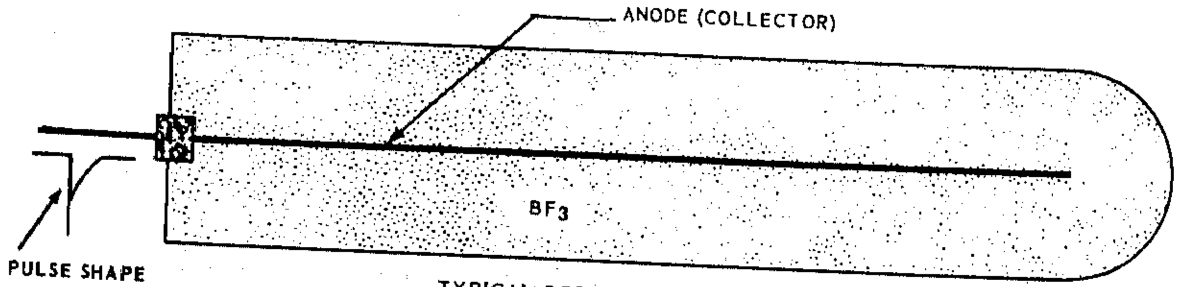
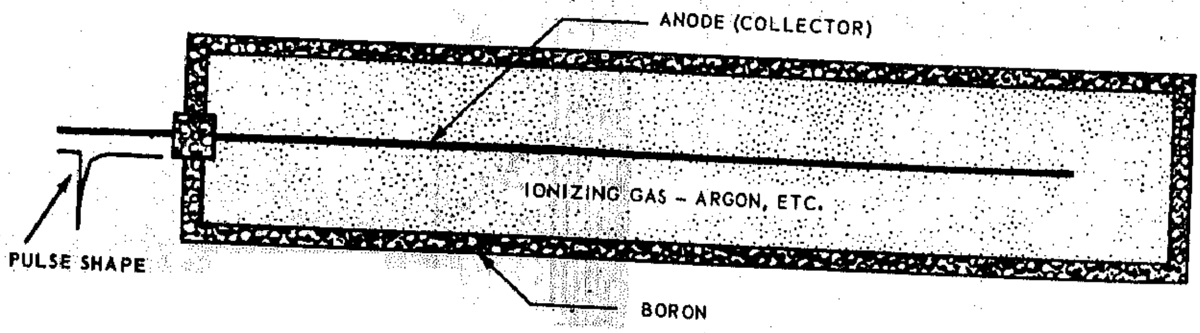


Figure 11 Photomultiplier Tube



TYPICAL BORON CHAMBER



SOLID BORON – LINED NEUTRON CHAMBER

Figure 12 Boron Chambers

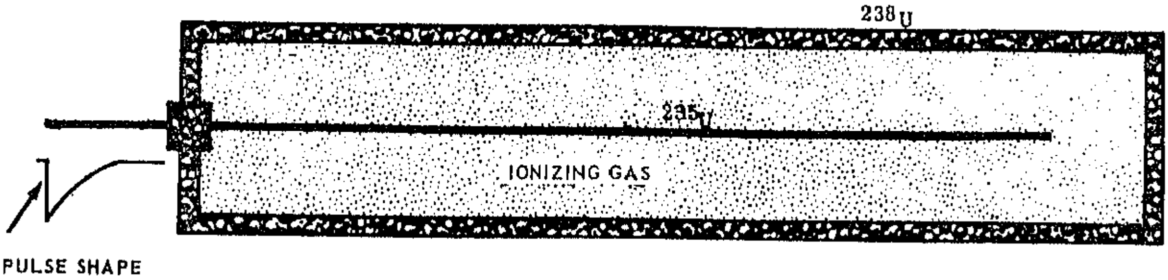


Figure 13 Fission Chamber ^{235}U, ^{238}U

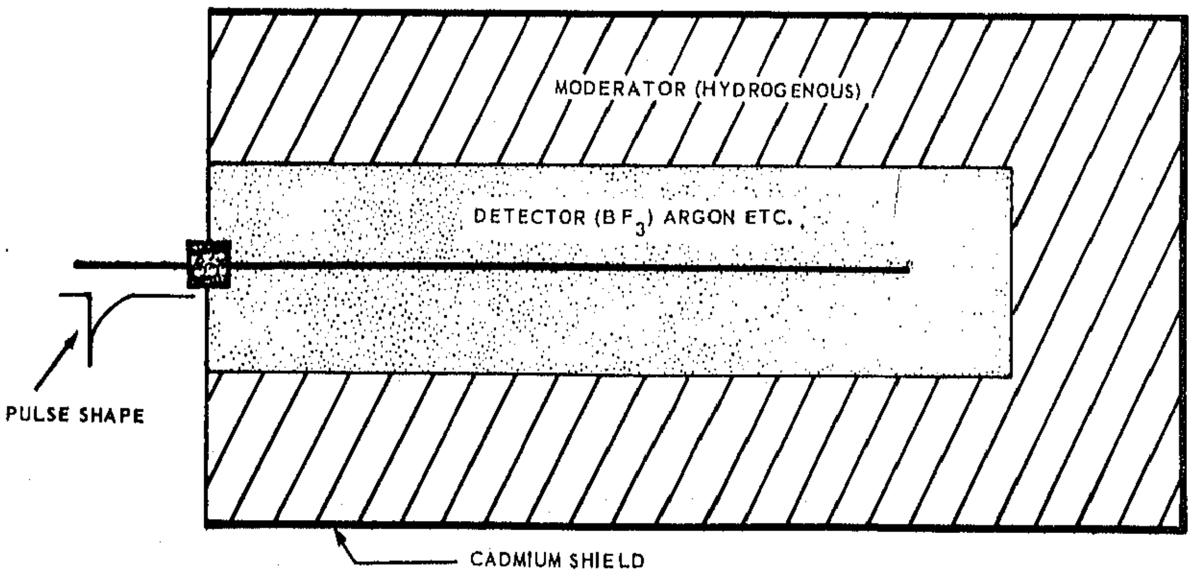


Figure 14 Fast or Slow Neutron Chamber

SECTION 13

ALPHA SURVEY INSTRUMENTS

Several types of instruments are available for alpha detection including ion chambers, proportional counters, scintillation crystals and solid state detectors. There are many variations in each of these types of radiation detectors. Many parameters, such as probe geometry and sensing gas, can be changed to yield instruments with different characteristics, even though they might use the same detection principle. This chapter describes two types of alpha detecting instruments: the gas proportional counter and the alpha scintillation detector.

> Note: The following is indicative of typical radiation instrumentation. Reference to a specific instrument is soley for illustrative purposes and should not be construed as a recommendation or endorsement of the instrument. Many radiation detection instruments are available and each one may have some distinct advantage over the others.

<u>Gas-Filled Proportional Alpha Counter PAC-4G (Figure 1)</u>

The probe is rectangular with a thin (0.85 mg/cm^2) aluminized mylar face with a sensitive area of approximately 50 cm^2. The internal anode consists of a single wire (0.001 inch diameter) fashioned in a rectangular loop around four small insulated posts. This wire gives the effect of a double anode. An exhaust valve on the top of the probe allows propane gas to escape and maintains pressure inside the probe which is slightly greater than ambient. The probe is connected to the instrument case by means of a special cable. This cable delivers voltage to the probe, acts as a carrier for the signal pulse from the anode, and also provides a passage for propane gas to the probe.

The signal pulse is returned from the probe through the cable connector to the instrument where it is amplified and shaped to a standard size pulse which is then fed to the count rate meter.

The electronic components of this instrument are found in the upper half of the instrument case (Figure 2). Components and functional modules are separately mounted on transistorized printed circuit boards and are replaced by pulling out the faulty board and plugging in a new one. The operating range of the instrument is between -40°F. and +140°F. However, changes toward the extremities of the operating temperature will affect calibration, primarily because of the resulting drift in the HV power supply and stress on the meter itself.

Power for instrument operation is supplied by five standard "D" size cells of any type commercially available (carbon-zinc, mercury, nickel-cadmium, alkaline).

Propane is used as a counting gas to increase instrument sensitivy. The lower half of the instrument case houses the gas supply system (Figure 3). A small gas bottle, similar to those used on commercially available torches, contains liquified propane sufficient for approximately 24 hours of continuous operation. The propane must be "pure" grade since the impurities in commercial grades are detrimental to the instrument. A regulator valve controls the gas pressure and two needle valves control the flow rate.

A three-position valve on the side of the instrument case controls the gas flow to the probe (Figure 4). In the OFF position (all the way in), the gas is shut off. The OPERATE position (half way out) allows gas to flow to

the probe. In the FLUSH position (all the way out), gas at slightly greater pressure than the operating level flows rapidly to the probe removing air and other impurities from the chamber during instrument warm up. The instrument will not operate properly until this operation is complete.

The first needle valve (No. 1) is always adjusted before the second needle valve (No. 2) (Figure 5). With the gas selector in the OPERATE position, the gas escaping from the gas exhaust port is ignited and the valve adjusted to produce a one-half inch flame. Then, with the knob in the FLUSH position, the No. 2 needle valve is adjusted to yield a one-inch flame. After adjusting the gas flow, the flame is extinguished and should not burn while monitoring with the instrument.

Calibration of the PAC-4G actually entails four steps: (1) Gas flow adjustment; (2) Sensitivity adjustment; (3) High voltage adjustment; (4) Calibration to standard sources.

The sensitivity adjustment is made by turning the sensitivity potentiometer (inside of instrument) fully clockwise then counterclockwise to a two millivolt indication on a volt meter.

High voltage adjustment is accomplished by plotting voltage versus the instrument response in counts per minute (a plateau). An alpha source is placed under the instrument probe and the voltage is adjusted in increments by the HV screw adjustment on top of the instrument case (Figure 6). The resultant curve will have a flat plateau (Figure 7) from which the operating voltage setting can be determined. When the PAC-4G is used at significantly different altitudes other than the altitude at which it was calibrated

(1,000 feet difference or more) the plateau may shift sufficiently to require recalibration (Figure 8). It also might be desirable to readjust the high voltage in the presence of high energy beta.

Standard sources are placed under the probe and the respective potentiometers inside the instrument are adjusted so the instrument response corresponds to the value of the source. These adjustments are made by lifting off the upper portion of the instrument and turning the potentiometers inside the instrument. When lifting the upper electronics from the instrument case, an insulated screwdriver should be placed between the high voltage contact and the instrument chassis to discharge the high voltage power supply.

1. Instrument Operation

   a. Pull the gas control knob out to the FLUSH position. Allow approximately five minutes to flush the probe. At the end of that time the knob is placed in the OPERATE position.

   b. Immediately after starting the gas flush, turn the scale selector switch from OFF to ON. Fifteen to twenty minutes warm-up time should be allowed before monitoring. Even though the instrument is transistorized, it does require this stabilization time.

   c. The meter face indicates the range from 0 to 500,000 counts per minute on a linlog display. The black needle indicates from 0 to 5,000 counts per minute; the red needle from 5,000 to 500,000 counts per minute. There is no range switching required. The meter is actually two meters which overlap for continuous readout.

   Alpha particles are emitted at random, and fluctuations in the meter pointer are to be expected. A reading may be obtained from the middle

of the extremes. Proper probe placement is extremely important. Figure 9 shows the effect of the probe distance from the source.

2. Routine Maintenance

   a. Blow dust from instrument case and internal components.
   b. Visually check wiring and components to find broken or dirty contacts.
   c. Tighten screws and nuts; do not change the high voltage discriminator or scale calibration potentiometers.
   d. Inspect battery cover plate and spring contact to insure proper connection.
   e. Check probe face for punctures. If any are found, inspect anode wire for damage and repair punctures or replace probe face.
   f. Adjust needle valves for proper gas flow. If the gas bottle is empty, it may be changed by removing the bottom half of the instrument case and unscrewing the gas bottle. If there is an audible "pop" when the bottle is removed, it has sufficient gas. An empty bottle can be identified by its weight difference when compared to a full bottle. A new bottle is added simply by screwing it in place, hand tight only.
   g. Run plateau curve of detector voltage versus cpm.

Contamination of the probe occurs when radioactive material adheres to the probe face during monitoring. The contamination may not be visible, but nevertheless may be sufficient to give reading. The probe face is very fragile and can easily be punctured. Therefore, extreme care must be used during decontamination.

Contamination can generally be removed by washing gently with cotton using an alcohol and water solution. If water gets inside the probe, it can short the anode and the probe must be dried out before it will be operable. Put the gas valve in FLUSH position to keep water out. A less preferable means of decontamination is to wipe the probe gently with clean cotton or a soft (camel hair) brush. If the probe cannot be decontaminated, it should be changed.

Should the probe face be punctured during use in the field and the situation demands its continued use, a small hole in the probe face can be patched with a small piece of masking tape or cellophane tape. The tape will shield alpha particles and the sensitive area will be reduced accordingly.

If alpha radiation is to be measured in an area also contaminated with beta radiation, the instrument must be checked for beta sensitivity. Cover the surface being monitored with a sheet of clean paper. If a meter indication is noted, either the probe is contaminated or the instrument is measuring beta activity. If a uniform reading is obtained when the probe is held in the air, it has become contaminated. If necessary, monitoring can continue by subtracting the contamination from the total counts. If the instrument is measuring beta radiation, the high voltage (HV) must be reduced. Turn the HV control counterclockwise until there is no meter indication or "clicks" from the speaker.

Changing the HV control setting may change calibration of the instrument. Therefore, calibration must be checked after this readjustment is accomplished.

Alpha Scintillation Counter PAC-1S (Figure 10)

The PAC-1S detector utilizes zinc sulfide (ZnS) as the phosphor. The electric pulse is generated and amplified by a photomultiplier tube.

The probe face is aluminized mylar and has a sensitive detection area of 59 cm^2. Immediately under the mylar is a layer of aluminum Dutch leaf (very thin strips of foil) to allow alpha particles to penetrate and to prevent light from entering the probe. A phosphor plate has powdered ZnS held to it by an adhesive. A prism concentrates the light photons resulting from alpha interaction with the phosphor and reflects the light 90° to the probe releasing electrons in the photocathode and amplifies the number of electrons through its successive dynodes. Figure 11 illustrates a typical probe.

The electronics are similar to those of the PAC-4G. However, in this case, the amplifier and trigger are on a single card. Power is supplied by five standard "D" cells or RM-42 mercury cells, with a life expectancy of 100 operating hours.

The temperature range for proper operation of the PAC-1S is +10°F to +130°F. This range may be extended by substituting a wet cell power supply for dry cell batteries. The meter accessory card should be changed to reflect the new range (-40°F to +130°F).

Determination of the proper operating plateau is somewhat different than the PAC-4G. The discriminator (Figure 12) is first turned completely counterclockwise. Turning the discriminator gradually clockwise increases its sensitivity. At low settings, only a few alpha particles can be

detected. Sensitivity increases until a relatively narrow plateau is observed. This is the operating point. Further increase in sensitivity causes the "dark current," or noise transients of the photomultiplier, to be detected and a rapid increase marks the end of the plateau.

After the plateau is established, further discrimination may be required as the scintillator is somewhat sensitive to both beta and gamma. There are two alternatives: the beta and gamma response can be noted and subtracted from the total while monitoring for alpha or the discriminator can be turned counterclockwise until there is no response to beta or gamma.

To place the instrument in operation, the range selector switch is turned from OFF to any of the range positions. After a few seconds warm-up, the instrument is ready for use. The meter indicates 0-2,000 cpm and the four ranges are X1, X10, X100, and X1,000 cpm. This allows a maximum of 2,000,000 cpm. There is no multiplier shield available for the PAC-1S.

In areas of very high alpha contamination levels, the PAC-1S will begin registering counts with the probe more than one inch above the surface. As the probe is gradually lowered, the response will increase and go off scale. Bringing the probe still closer to the surface will cause the meter response to decrease and it may not give a reading in an area of very high contamination. In this case, pulses are being formed so rapidly that the photomultiplier tube does not have time to completely pass off a pulse before another is present and several pulses are indicated as a single pulse.

Alpha scintillation detectors can be sensitive to gamma radiation. Figure 13 shows the effect of cobalt-60 gamma rays on the PAC-1S. The scintillation

principle used in the PAC-1S logically explains its sensitivity to light leaks. A hole which is not visible to the naked eye can cause sufficient light leakage to render the instrument inoperable. Light leaks can be indicated by alternately exposing the probe to light and shading it. Significant variations in response suggest a leak. If earphones are being utilized with the instrument, a characteristic "hissing" noise will be heard. By shading various zones of the probe, the area of the hole can be found and sealed off with a drop of black lacquer or black plastic tape. The spots will shield alpha particles.

1. Routine Maintenance

   a. Remove any dirt and dust from the exterior of the instrument cable and probe.

   b. Inspect the probe window carefully for indication of punctures.

   c. Check the probe window for light sensitivity. Remove cover plate and check batteries under load. Replace batteries supplying less than 85 percent of their normal power.

   d. Check high voltage, using an electrostatic voltmeter. Normal voltage is approximately 1,250 volts.

   e. Check plug-in boards for tight contact.

   f. If the instrument has been used in a very dusty area, remove the probe face and wipe optics and mirrors gently with a very soft cloth.

   g. Inspect all insulators in the probe connector chassis and probe.

Probe decontamination procedures are the same for the PAC-1S probe as those shown for the PAC-4G probe.

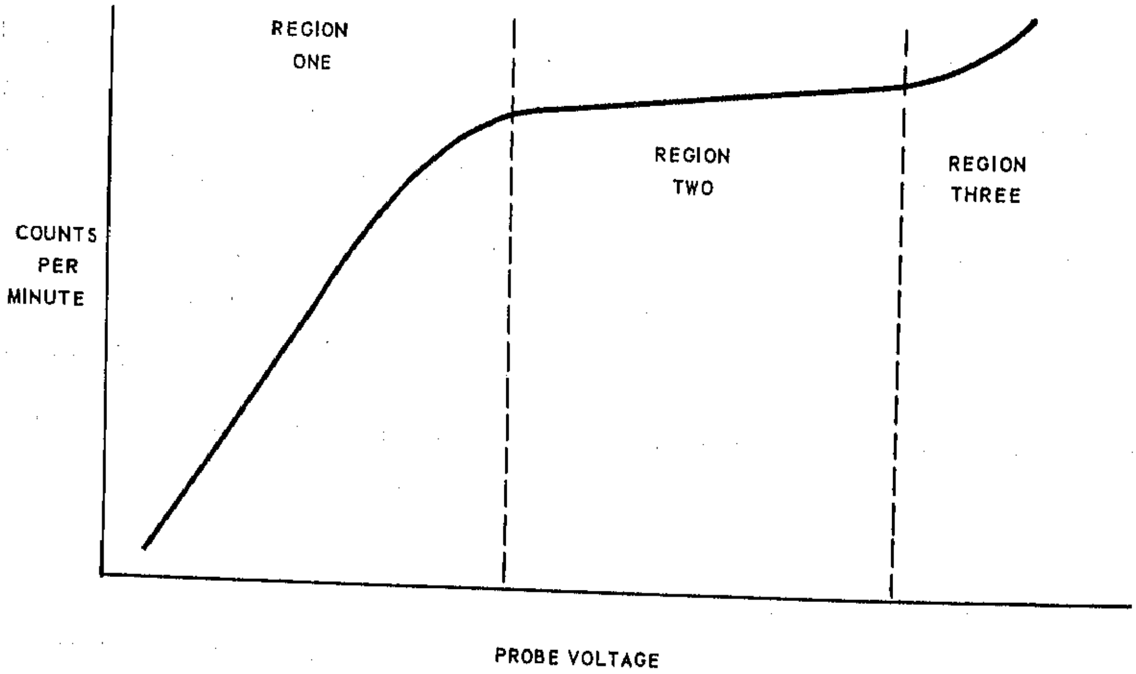


Figure 7. Plateau Curve

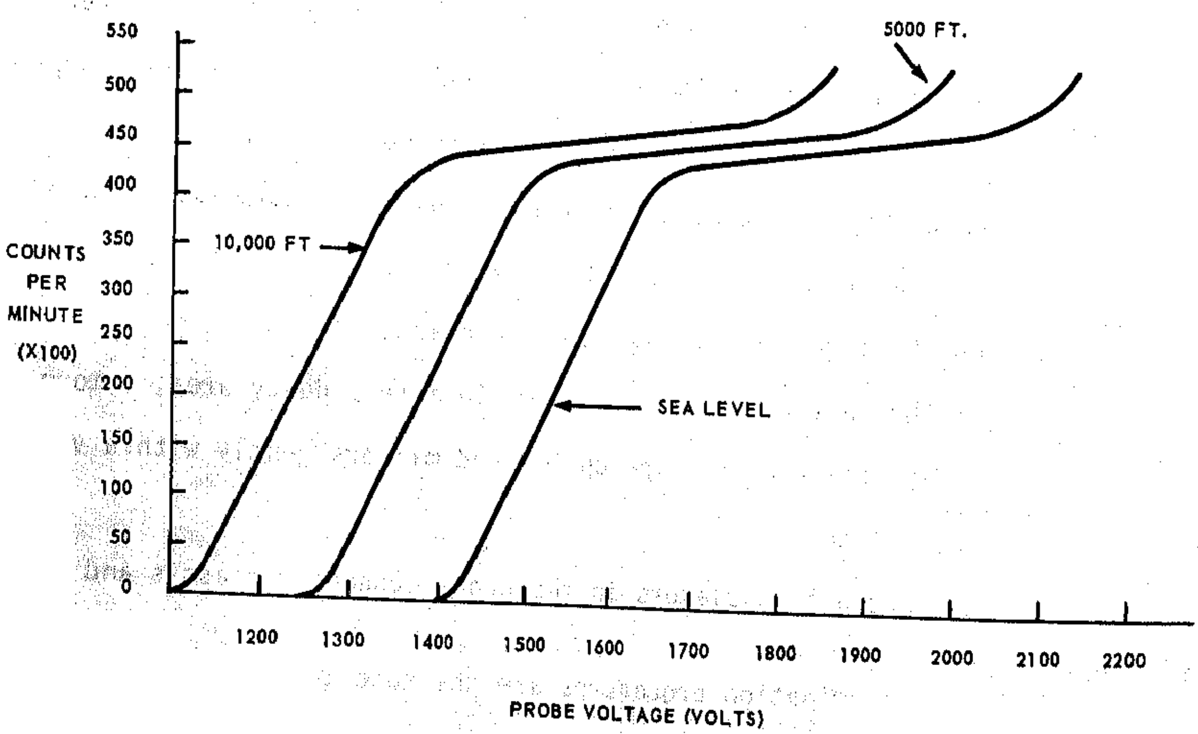


Figure 8. Altitude Shift

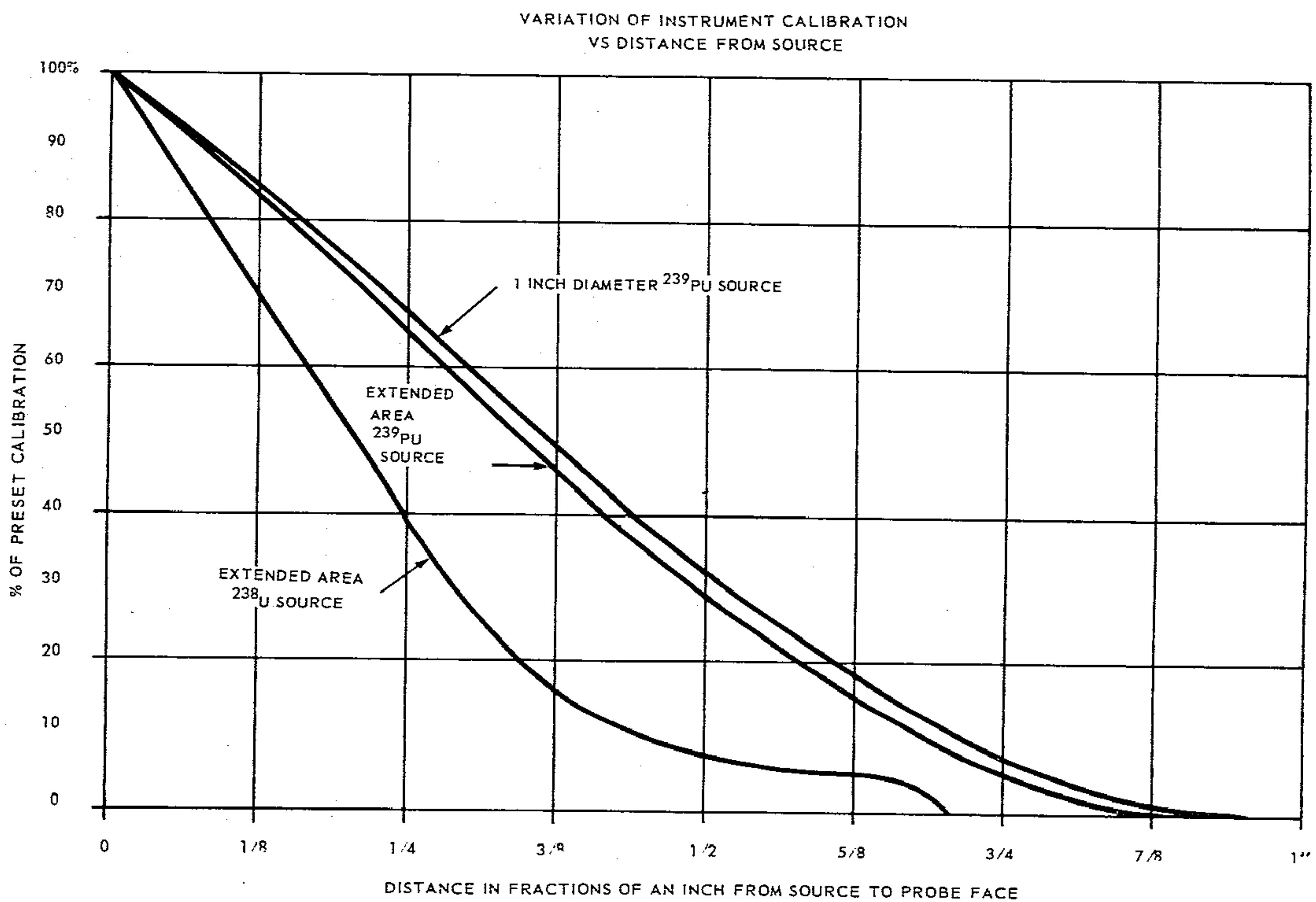


Figure 9. Variation of Instrument Calibration vs Distance From Source

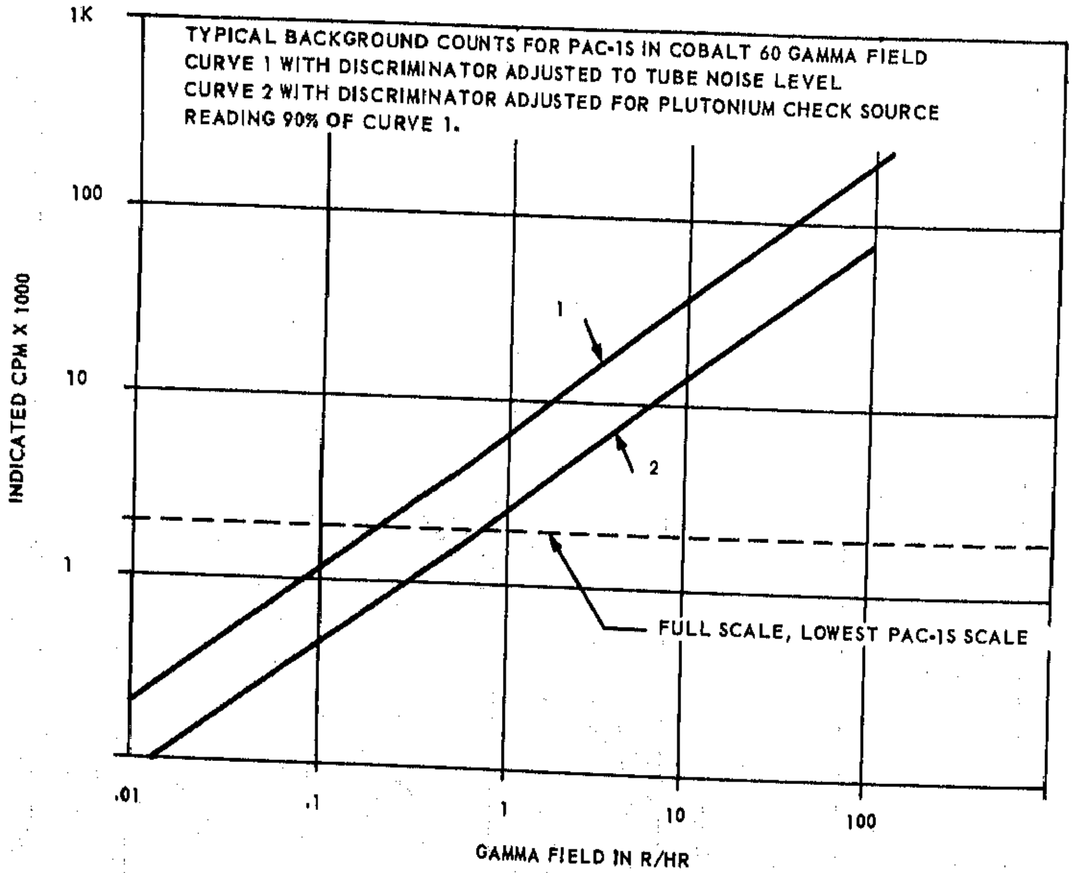


Figure 13 Typical Background Counts for PAC–1S in Cobalt-60 Gamma Field

SECTION 14

BETA, GAMMA DETECTION INSTRUMENTS

Beta and gamma radiation is usually detected by GM detectors, ion chambers, and scintillators. Of these types, there are many variations. Three such instruments will be described in this chapter to lead to a better understanding of all beta, gamma instruments.

NOTE: The following is indicative of typical portable radiation instrumentation. Reference to a specific instrument is solely for illustrative purposes and should not be construed as a recommendation or endorsement of the instrument. Many radiation detection instruments are available and each one may have some distinct advantage over the others.

E-520 Geiger Counter (Figure 1)

The E-520 is a portable, compact, lightweight, weather-resistant instrument which utilizes Geiger-Mueller tubes for the detection and measurement of beta and gamma radiation. All electronic components are housed in a 4" x 8" x 7 3/4" aluminum casing which weighs approximately four and three-eighths pounds fully equipped. The instrument is equipped with a phone jack for aural monitoring that can be plugged into head phones or local speaker with no effect on the calibration. The instrument has a reset button which is used to quickly return the meter to zero. The E-520 is capable of measuring from zero to 2000 mR/hr gamma, and from zero to 200 mR/hr beta plus gamma. The instrument has a movable shield to differentiate between beta and gamma activity. Two GM detector tubes are utilized. For dose rates up to 200 mR/hr, the external GM tube is used. For gamma only dose rates up to 2000 mR/hr, the internally mounted GM tube is used. Range switch positions of the instrument are OFF, X100, X10, X1, X0.1, and X.01. The instrument

scale is 0-20 mR/hr in five linear ranges of 0.2, 2.0, 20, 200, and 2000. Accuracy on the X1.0, X0.1, and X.01 scale is ±8%. Accuracy on the X 10 scale is ±15%. The X 100 range switches to the internal GM tube which is accurate to ±10%. Accuracy, as stated, is referenced to full scale for the respective scales.

This GM instrument will differentiate between β and γ radiation. However, the monitor should understand that usually the instruments are calibrated with the shield closed to indicate γ in mR/hr. An open shield measurement shows the total impact of γ plus β on the detector. Some instrument dials are marked in counts per minute; to differentiate between γ and β, the closed shield measurement should be subtracted from the open shield measurement, and the balance can then be reported as beta plus soft gamma in counts per minute. Since beta particles cannot penetrate the instrument case to reach the internal probe, only gamma is measured on the X 100 range. Both detector tubes have been checked at intensities up to 1000 R/hr without saturation and the meter remains at full scale on all ranges. When the tube saturates, however, it will not read zero but will hover around mid-scale. The internal detector sensitivity for cesium-137 is approximately 100 cpm per mR/hr. Sensitivity of the external detector is approximately 1200 cpm per mR/hr for cesium-137.

Power for the instrument is provided by two D size cells of any type; i.e., carbon, alkaline, mercury, or nickel-cadmium (single charge). Battery life is dependent on which type of batteries is used, but is typically from 200 hours (nickel-cadmium) to 700 hours (mercury).

Model 14C Geiger Counter (Figure 2)

The Model 14C Geiger Counter is a portable, compact, lightweight, weather-resistant beta-gamma survey meter. All electronic components (as shown in Figure 3) are housed in a 3 1/2" x 3 1/2" x 7" aluminum case. The instrument weighs approximately three and one-half pounds including batteries. The instrument is equipped with either an audio phone jack or a built-in piezo-electric element (Unimorph) which is driven by an oscillator to emit audio signals. Use of a headset or the audio speaker does not affect calibration of the instrument. The instrument has a reset button on the control panel which is used to quickly return the meter to zero. The Model 14C will measure gamma from 0-2000 mR/hr and beta-gamma from 0-200 mR/hr. It utilizes two GM detector tubes. The external tube, which is housed in a movable and rotatable metal shield, is used to measure beta plus gamma up to 200 mR/hr. Rotation (opening and closing) of the movable shield allows differentiation between beta and gamma. The internal detector measures only gamma up to 2000 mR/hr. Both detectors operate at 900V.

The range switch positions are ON, OFF, X100, X10, X1, X0.1, and X.01 (Figure 4). The meter scale is a 0-20 linear scale which allows five full-scale indications of 0.2, 2, 20, 200, and 2000 mR/hr. The internal detector only responds on the X100 range and indicates gamma only. The instrument is accurate to $\pm 8\%$ on the X1, X.1, and X.01 scales, $\pm 15\%$ on the X10 scale, and $\pm 10\%$ on the X100 scale. Accuracy is referenced to full scale of the meter.

Although the instrument will differentiate between beta and gamma radiation, it is normally calibrated with the shield closed to indicate gamma in mR/hr. Open shield measurements indicate the total interaction of beta plus gamma within the detector. Some meter faces are marked in counts per minute only,

and as in the case of the Model 14C, some are marked in both mR/hr and counts per minute. To differentiate between beta and gamma, the user must take a closed shield measurement and an open shield measurement. The closed shield reading is then subtracted from the open shield reading and the difference reported as beta in counts per minute or mrad. Since beta particles cannot penetrate the instrument case to reach the internal detector, any measurements taken on the X100 scale should be reported as gamma in mR/hr.

Both detectors have been exposed to dose rates up to 1000 R/hr without saturation and remain at full scale (pegged out) on all ranges. If the detector were to saturate, the meter would not remain at full scale but would drop off to zero, or would "hover" around midscale or some other point characteristic of the particular instrument.

Power for the instrument is provided by two D battery cells of any type, i.e., carbon, alkaline, mercury, or nickel cadmium. Battery life is dependent on which type of batteries are used but is typically from 200 hours (nickel cadmium) to 700 hours (mercury). For prolonged low temperature operation, either alkaline or rechargeable NICD batteries are recommended.

The instrument is operational from -40°F to +140°F with cold weather batteries. Above 32°F, satisfactory operation can be obtained with regular carbon or mercury batteries.

Detector high voltage may be adjusted if necessary to accommodate other size GM tubes or scintillation probes. The control for setting the HV is located inside the instrument.

The instrument is normally calibrated with a radioactive source of known activity by placing the detector in a known radiation field and adjusting the caliabration range potentiometers for desired readings on each individual scale. It can also be calibrated using a "pulser" to adjust the count rate on each scale and then checking it with a radiation source. The latter method will be somewhat different, and if used, will probably require some method of conversion with meter indications to arrive at a true reading.

Model PIC-6A Portable Ion Chamber (Figure 5)

The PIC-6A is a small, lightweight portable survey meter which measures the exposure rate of gamma radiation. It utilizes a gas-filled ionization chamber operating in the proportional (gas multiplication) region. Six decades of exposure rate, from 1 mR/hr to 1000 R/hr, may be measured in two ranges of three decades each. A single rotary switch marked OFF, BATT, R/hr, and mR/hr operates the instrument. An optional feature of the instrument is a beta window, located in the bottom of the instrument case, which may be used for detection of beta particles.

The detector (ion chamber) is of the coaxial (cylindrical) configuration similar to the GM tube with an active volume of 11 cubic centimeters filled with pure grade propane to approximately 60 cm Hg pressure. The detector is made of stainless steel with 30 mg/cm^2 wall thickness and is sensitive to gamma energies from 60 KeV to 1.3 MeV.

The meter scale is a logarithmic presentation of 1-1000 in three decades of 10, 100, and 1000. With the selector switch on "mR/hr" the meter will indicate 1 mR/hr to 1000 mR/hr; on the "R/hr" position, it indicates from 1 R/hr to 1000 R/hr. Response time of the instrument is essentially

instantaneous on the R/hr range. On the mR/hr range, response time is approximately two seconds per decade increasing and three seconds per decade decreasing. Linearity or accuracy of the instrument is within plus or minus 20 percent of the indicated reading.

Power is supplied to the instrument by two small 9-volt batteries in a parallel configuration. The instrument will operate on one battery; however, battery life will be less than one-half that obtained with two batteries. Battery life is a function of battery type, age, and operating temperature. Battery life at room temperature is nominally 60 hours carbon-zinc, 60 hours alkaline, and 120 hours mercury. The instrument is operational from -10°F to +140°F with less than 0.5% shift in readings per degree Fahrenheit.

Detector HV typically is quite high for a portable survey meter and varies as a function of the output current from the chamber which results from the intensity of the radiation being measured. At the lower end of the scale (mR/hr), voltage is approximately 2800-3000 volts. At the top end of the range (R/hr), voltage drops to approximately 1700-1800 volts due to heavy current generated in the detector. The PIC-6A weighs three and one-quarter pounds equipped with mercury batteries and is 5 5/8" high x 8 3/8" long x 4" wide. It is splashproof and dust-resistant for use in most outdoor situations.

SECTION 15

NEUTRON DETECTION INSTRUMENTS

Neutrons produce indirect ionization through bombardment of other materials. This bombardment of a target material causes ionization as a result of two general reactions, a nuclear reaction or a recoil reaction. A nuclear reaction caused by a neutron entering the nucleus of an atom and being captured may result in the release of an alpha particle. The alpha particle then causes ionization which is detectable by conventional means. A recoil reaction occurs when a neutron collides with a hydrogen atom. In this case the force of the collision causes a proton to recoil from the nucleus at high velocity and with considerable ionizing ability.

Methods of detection may vary according to the energy of neutrons to be detected. Slow neutrons are detected by nuclear reactions with either boron-10 or in material which has high cross section for fission with low energy neutrons. The boron chamber is the most common neutron detector. The detector is a small cylinder containing boron trifluoride (BF_3) gas or boron-10 in solid form. In the latter case the cylinder wall is lined with a thin layer of boron and the cylinder is filled with a noble gas. This detector functions as a proportional counter to detect the alpha particles released from the $^{10}_{5}B(n,\alpha)^{7}_{3}Li$ reaction.

Fission chambers are constructed similiarly to the solid lined boron chamber. For slow neutron detection enriched ^{235}U is used to line the chamber wall since it will fission readily when bombarded by slow neutrons. This chamber is not used extensively because of the prohibitive costs and limited supply of ^{235}U which fissions with fast neutrons and is readily

available. Pulse counting ion chambers or proportional detectors can be used as fission chambers.

Scintillation detectors are also used in neutron detection. The energy of neutrons detected by this method is a function of the scintillation material used. The scintillator is impregnated with a material which gives off ionizing radiation when bombarded by neutrons. The scintillator may either be solid or liquid in form. Normally solid crystals are used to detect fast-neutrons by recoil reaction. The crystal is impregnated with material rich in hydrogen. Liquid scintillators are used to detect slow neutrons by adding boron to the phosphor material. The hydrogen in the material incorporated in a scintillation crystal or surrounding a boron chamber serves to slow fast neutrons for detection.

A neutron chamber's usefulness may be increased when it is surrounded by a moderator. This will increase instrument efficiency and more neutrons will be detected. However, detection of neutrons with differing energies should have some means of discrimination. This is accomplished by surrounding the moderator with a material such as cadmium which captures thermal and slow neutrons. Slow or fast neutrons can be detected by using a moderator with a cadmium shield in conjunction with the bare boron chamber.

Neutron detection instruments are more complicated and bulky than beta-gamma instruments. A multitude of neutron instruments have been designed and developed. This chapter will describe the Eberline Instrument Corporation portable neutron counter Model PNC-1 which utilizes a gas-filled BF_3 proportional detector and is capable of detecting either slow or fast neutrons.

Model PNC-1 Detector (Figure 1)

This instrument utilizes a boron trifluoride filled chamber in conjunction with a paraffin moderator and cadmium shield. The detector assembly is constructed to allow the chamber to be moved in or out of the moderator and cadmium shield. Fast neutrons are detected by inserting the detector into the moderator and cadmium shield. Slow neutrons are detected when the probe is outside of the moderator.

The upper half of the instrument case contains the instrument electronics. These electronic components include a high voltage power supply, a low voltage battery pack supply, an amplifier trigger circuit, a rate meter integration circuit, and a zero to 20 microamp meter. Provision is also made for audible monitoring. The instrument read-out is presented on a linear meter scale in events per minute (0 to 500). The electronics are transistorized and mounted on small boards or plug-in modules. A block diagram for the PNC-1 is illustrated in Figure 2.

Controls for operation of the instrument are located on the top of the instrument case as shown in Figure 3. These controls consist of a range selector switch, a discriminator control, and a reset switch. Calibration controls are internally mounted. The range selector switch is used to select the desired range for operation and also acts as an ON-OFF switch. To read the neutron field strength multiply the meter response by the number indicated on the range switch. There are four positions on the switch, X1, X10, X100, and X 1,000. The reset switch is used to discharge the integration capacitors, allowing the meter reading to rapidly return to zero. The discrimination control is set at the factory

and will not need readjustment for normal monitoring. If readjustment is necessary, the instrument should be placed in a gamma radiation field of 10 R/hr and the discriminator adjusted for approximately 25 events per minute on the meter.

To count slow neutrons remove the detector from inside the moderator and cadmium shield. To detect fast neutrons the detector is inserted into the moderator until the detent that holds the probe in place is engaged.

The time between particle emissions can vary greatly. When the interval between particles is less than average the meter will indicate high. If the interval is greater than average the meter will indicate low. The instrument is designed to cancel out much of this variation. The operator should, however, observe the meter for a sufficient period of time to determine the average reading. This fluctuation will normally appear only in the lower range of operation.

Calibration of the PNC-1 is accomplished in the following manner: The electronics are first calibrated with a pulse generator to assure a correct count rate. The instrument is then placed in a gamma radiation field for compensation (discriminator adjustment) and finally checked at several points on the meter scale with a neutron source of known flux.

Since the PNC-1 read-out is in events per minute and normal terminology refers to n/cm^2 per second it may be necessary to convert these factors. Figure 4 illustrates the energy response of the detector and is to be used for converting the meter response in events per minute to n/cm^2 per second.

1. The following procedure will achieve the desired conversion:

   a. Find the energy on the graph corresponding to the energy of the neutrons being monitored.

   b. Follow this energy down till it intersects the respective response curve.

   c. Read the correction factor off the left hand side of the graph.

   d. Divide this correction factor into the meter reading in events per minute to obtain n/cm^2 per second.

   e. The correction factor can also be divided into one and the result multiplied by the meter reading.

2. Routine maintenance procedures for preliminary check-out of the instrument are as follows:

   a. Turn the instrument off.

   b. Wipe the instrument case off with a clean damp cloth to remove dirt and dust.

   c. Visually inspect the exterior of the instrument for damage.

   d. Remove the detector and cable attaching it to the instrument and short the high voltage contact to the chassis to discharge the high voltage supply.

   e. Examine the high voltage connectors, both at the probe assembly and at the instrument case, for dirt and grease. If they appear to be dirty, clean with alcohol. Do not use a solvent which might leave a residue.

   f. Remove the electronics from the instrument and make a thorough inspection to ascertain if there are any broken leads, components, loose screws, etc.

g. Remove batteries and check under load.

h. Clean all battery contacts and replace batteries as necessary.

i. Check selector switch and clean or repair if needed.

j. Place the instrument in the case and attach detector assembly and cable.

k. If the detector has been replaced in the field, the discriminator must be readjusted.

l. Check response with a neutron source.

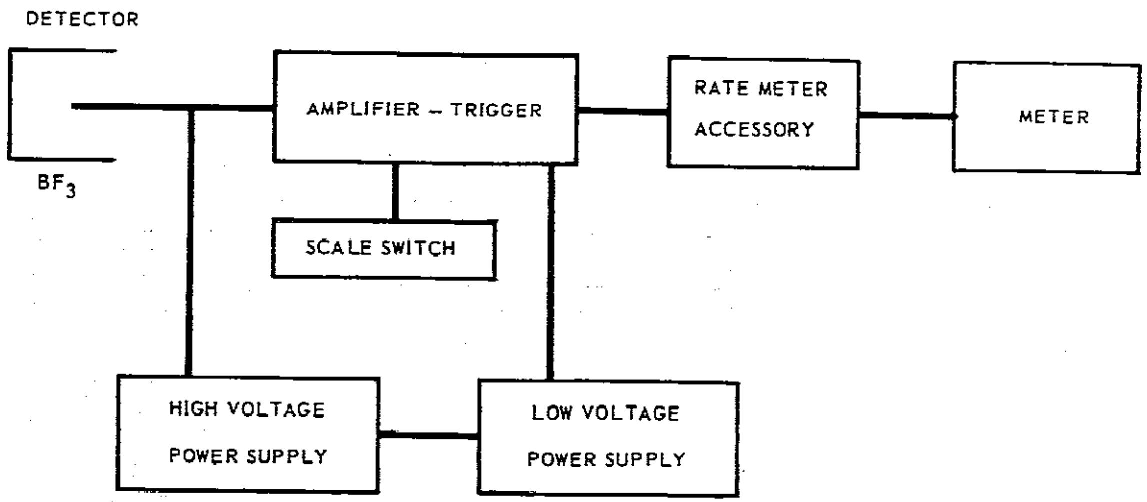


Figure 2. PNC-1 Block Diagram

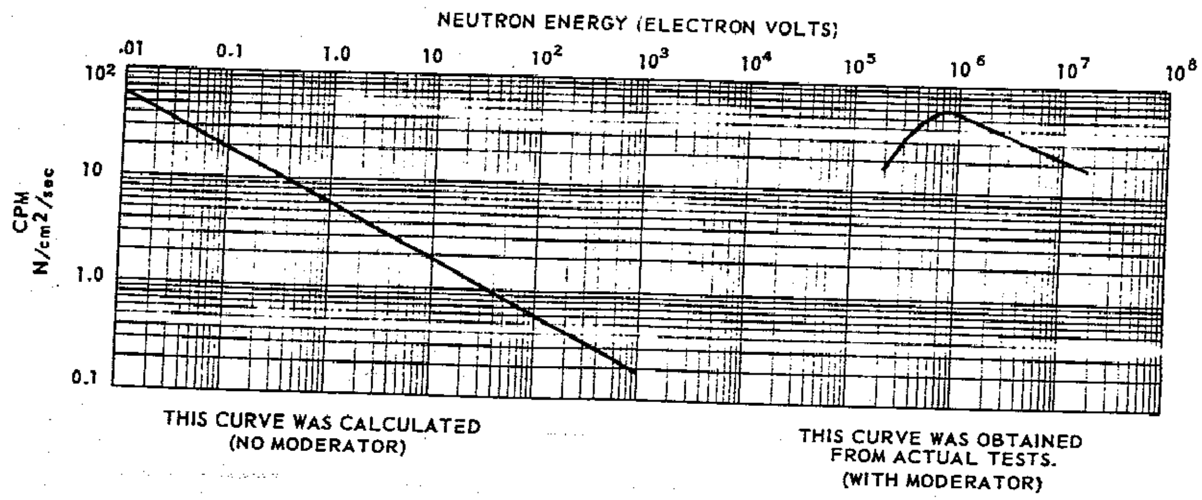


Figure 4. PNC-1 Energy Response

SECTION 16

COUNTING EFFICIENCY

SAMPLE PREPARATION

The type of radiation to be detected and the chemical and physical form of the sample determine the type of detector to be used. For common types of detectors used, ideally the sample should be weightless (to negate self-absorption losses) and should be either a point source or spread uniformly over a given area (to facilitate replication of geometry).

With alpha or soft beta radiation particularly, thin deposits of sample are preferred. In some instances, it may be possible to concentrate the radioactive material by chemical or physical means such as electro-deposition, precipitation, evaporation, etc. In other instances, notably with carbon-14, the material may be converted to a gas which can be counted in an internal-type detector.

With gamma emitters, absorption effects are much smaller, which allows thicker samples to be counted. Using high-efficiency gamma detectors, soil or liquid samples can be counted directly.

ABSOLUTE COUNTING

Absolute counting requires the evaluation of the observed counting rate in terms of the disintegration rate. The ratio of observed counting rate to disintegration rate is known as the counter efficiency which can be determined for any instrument by either of two methods: (1) by measurement of the individual factors (geometry, absorption, and scatter) which determine the efficiency, or (2) by comparison with a known standard source of radioactivity.

Measurement of Individual Factors

By this method, the efficiency is equal to (geometry factor) x (scatter factor) x (absorption factor). These factors are defined and explained as follows:

Geometry - The prime factor affecting the efficiency of any detector is the position of the sample relative to the sensitive volume of the detector. The geometry is defined as that percent of solid angle about a source which is subtended by the sensitive volume of the detector. In the case of an end-window G-M counter, increasing the vertical separation between the sample and the face of the tube would lower the geometrical efficiency by decreasing that solid angle. The geometry of end-window counters usually ranges from 1 to 30 percent. For an internal counter, where the sample comprises a portion of the floor or one wall of the counting chamber, the geometry is fixed at 2π, i.e., 50 percent.

The geometry (G) of an end-window detector using a point source may be calculated as follows:

$$G = 0.5\ (1 - \cos \alpha)$$

where: $\alpha = \tan^{-1} r/d$, r is the radius of the counter window and d is the distance between source and window.

The geometry may also be determined experimentally using a known source mounted such that scatter and absorption effects are negligible.

Scattering - The most important of the scattering effects is "backscattering," i.e., the reflection by the source support material of radiations emitted by the sample away from the sensitive detector volume. Backscatter is defined as the ratio of the number of counts achieved from a

sample mounted on any given material to the same sample suspended freely in air.

This scattering effect is a function of three variables: the energy of the radiation, the thickness of the source support, and the material employed in the source support.

The higher the energy of the radiation, the more scattering there will be. The higher the atomic number of the sample support, the higher the backscatter factor will be. Up to a certain thickness (known as the saturation thickness), the thicker the sample mount, the greater the backscatter will be. Backscatter factors may range as high as 1.6 for materials such as silver and platinum.

There are other scattering actions which take place with any counting arrangement including scattering from the source support structure, the walls of the lead shield and the walls of the tube itself, but these effects are minor when compared with backscatter, and will be constant for any sample in the same position.

To determine the backscatter factor, counting rates are compared using essentially weightless backing (sample mounted on a thin plastic film) and using the sample mount and support of interest. Experimentally determined backscatter factors have been reported in the literature and these are applicable for similar counting arrangements.

Absorption

There are two absorption effects which are important. The first is absorption taking place in the source itself. The second is that taking place in the air and detector window.

Self-absorption is most significant in the cases of alpha emitters, since extremely small amounts of material thickness are sufficient to completely absorb the alpha radiation. Carbon-14 with its low beta energy shows significant self-absorption effects at thicknesses of one milligram per square centimeter, while Phosphorus-32 (which has a maximum beta energy some ten times as large) will not be significantly affected until the sample thickness reaches values of from 15 to 20 milligrams per square centimeter.

Absorption taking place in the air and detector window would apply primarily to an end-window G-M counter in which case the thickness of air and window would have to be determined. The "equivalent window thickness" can be calculated by adding to the thickness of the tube window (given by the manufacturer), the thickness of air separating the source and the tube. To determine the latter in mg/cm^2, multiply the distance in cm by 1.2.

To determine the absorption factor (ratio of count rate without absorption to that with absorption), samples are prepared using a fixed amount of absorbing material. A plot of the count rate versus sample thickness can be extrapolated to zero thickness.

Comparison with Standard Source

A simpler method for determining counting efficiency is merely to compare the observed counting rate with the known disintegration rate of a standard reference source. Such reference sources are commercially available for a wide variety of radioisotopes. In this way the efficiency can be measured for similar samples on similar mountings placed in a similar shelf position. This method is usually employed in that it is easier, quicker, and perhaps more reliable.

Comparative Counting

Comparative counting is usually encountered in tracer studies where the objective is to determine relative source intensities rather than absolute intensities. Normally, sample preparation and mounting are identical for various samples counted so that there is no need to correct counting rates to absolute disintegration rates.

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SECTION 17

NUCLEAR COUNTING STATISTICS

The statistical nature of radioactive decay stems from the fact that radioactive atoms decay at completely random intervals of time. This concept will be considered here; some basic principles of statistics and techniques to handle data acquired by nuclear counting instruments will be mentioned briefly.

THE STATISTICAL NATURE OF RADIOACTIVE DECAY

Random Time Intervals

Why is radioactive decay statistical? If the decay rate of a particular radioisotope were determined to be one decay per minute, it might appear straightforward that in one minute, one count would be deleted; two minutes, two counts, and so forth. However, breaking the time interval down into seconds, would one of the group radioactive nuclei decay in the first ten seconds, after thirty seconds, or exactly every sixty seconds? Nuclei decay randomly and could decay over any time interval. The probability for any one nucleus to decay does not change with time. Therefore, a rate of one decay per minute is an average, probable rate, measured over a longer period of time. There is no way to determine which nucleus will go, because some will last, and some will not. Even with 100 percent efficient detection equipment, there will always be uncertainty in a nuclear measurement due to this random decay process.

Note that the statistical nature of radioactive decay has nothing to do with the statistical fluctuations associated with the electronic detecting equipment. It is solely a phenomenon of radioactivity. It is an error

that can't be removed by more careful measurement. It can be reduced by taking a larger count over a longer time, but by no other means.

Radioactive Decay Law

In 1905 the law of radioactive decay was deduced by Schweidler and was shown to be exponential in nature. This law, expressed mathematically is:

$$N = N_o e^{-\lambda t}$$

Where:

N	=	nuclei remaining after a time interval, t
N_o	=	nuclei at some original time
e	=	base of natural logarithms: 2.7183...
λ	=	decay constant for the particular radioactive element, and
t	=	elapsed time.

This law of radioactive decay was originally derived with only three assumptions: (1) The disintegration of an atom is subject to the laws of chance. (2) The probability of an atom decaying in a certain time interval is independent of the past history of the atoms. And (3) this probability is the same for all atoms of the same radioisotope.

A rough analogy could be drawn from tossing a coin. There are two possible outcomes: heads or tails. This corresponds to the nucleus, which either decays, or it does not decay. Over some time interval, the probability is 50%, as it is with each toss of the coin. Whether you have been tossing the coin for two minutes or three centuries, the probability of the next head is still the same. If a nucleus has not decayed for two minutes or three centuries, the probability that it will decay in the next second is the same

small but constant probability as for each of the previous seconds. And finally, no matter which of the billions of minted coins is flipped, the probability of receiving a head is the same for all, just as the probability of one nucleus decaying is the same for all similar nuclei. There are no "fired" ones more liable than the rest.

STATISTICAL PRINCIPLES

The fundamental frequency distribution governing random events is the binomial distribution. Binomial literally means two numbers and, in radioactive decay, pertains to the two possible outcomes: Either the atom decays or it does not decay. When the probability of an event occurring is small and constant (as in the case of disintegrating atomic nuclei), the Poisson distribution (a limiting case of the binomial) can be used to describe the frequency of occurrence. Both the binomial and Poisson distributions pertain to discontinuous variables (such as particle counting rates) which take on successive whole number integral values. For a moderately large number of events (>30), the "normal" or Gaussin distribution provides an adequate approximation easily applied to nuclear counting statistics. The statistical theory of errors is ordinarily based on this normal distribution.

Normal Distribution

The familiar "bell-shaped" curve is a plot of the normal distribution.

Figure 1 shows the frequency of occurrence of some event, x, plotted against the numerical value measured for that event. If student grades were graphed, the y-axis would be the number of students (frequency of occurrence) receiving grades while the x-axis would be the numerical or letter grade. The peak and center section would be the average or C

grades and contain the majority of students. The wings, or rare occurrences, coincide with the A and F students.

When considering nuclear counting statistics, the x-axis would depict the different counts or count rates measured while the y-axis would pertain to the number of times these different counts or count rates were observed (frequency of occurrence or observation).

Useful Terms

Three terms commonly used when describing a normal distribution are the "mean," the "standard deviation," and the "confidence level."

The Mean, $\overline{X}$, is the average value, the center (peak) of the distribution. If two counts of 5 and 7 were obtained, the mean would be 6, $[(5 + 7) \div 2]$.

The Standard Deviation, σ, is simply a parameter describing the uncertainty of a measurement and defines the spread or dispersion of the data. If nuclear data, or other Poisson distributed data is used it, is equal to the square root of the mean ($\sigma = \sqrt{\overline{X}}$). It concerns the distribution of deviations ($\overline{X} \pm \sigma$) from the mean ($\overline{X}$). If the total area under the curve of Figure 1 is considered 100%, then the individual observations that deviate from the mean or average value ($\overline{X}$), by more than one standard deviation ($\pm 1\sigma$), should be about 32% (if the sampled population follows a normal distribution). Thus, 68% of the individual observations should lie within the band $\overline{X} \pm \sigma$.

What does this mean? If a radioactive sample were counted many times, 68% of the observations (counts) should fall close to the mean value (within 1 standard deviation), while 32% of the observations should be outside the 1 standard deviation.

Note that the standard deviation estimates the uncertainty (error) in a measurement and is not a discrepancy (false measurement). The uncertainty in counting radioactive elements comes from the statistical or random nature of radioactive decay.

If 64 counts were measured, the standard deviation would be: $\sigma = \sqrt{64} = 8$. Thus 64 $\pm$ 8 indicates something of the certainty of the measurement.

The Confidence Level, or C.L., indicates the certainty of or confidence the experimenter has in a measurement. Since 68% of the area under the normal curve falls within $\pm$ 1σ standard deviation of the mean value, $\overline{X}$, the use of $\pm$ 1σ shows a level of confidence of 68%. A standard deviation of $\pm$ 1.64σ results in a 90% confidence level; $\pm$ 1.96σ is commonly used and gives a confidence level of 95%. For this example:

$$64 \pm 1\sigma = 64 \pm 8 \text{ for a 68\% C.L.}$$

$$64 \pm 2\sigma = 64 \pm 16 \text{ for a 95\% C.L.}$$

Thus, 68% of the time (if the counting experiment were reproduced many times) a value between 56 and 72 should be observed; while 95% of the time, the count should fall between 48 and 80 (assuming, of course, that the sampled population follows a normal distribution).

STATISTICAL TECHNIQUES

Count Rate

In nuclear counting experiments it is of more interest to know the count rate than the number of counts. The count rate (R) is simply the number of counts (n) divided by the counting time (t), or:

$$R = n/t.$$

The uncertainty (error) in the count rate is equal to: $\sigma = \sqrt{n} \div t$. This calculation assumes a negligible counting-time error. This is justified,

since modern clocks and timers are so accurate that the uncertainty in the time is insignificant.

Since $R = n \div t$, $n = Rt$ can be substituted into the rate error equation:

$$\sigma = \frac{\sqrt{n}}{t} = \frac{\sqrt{Rt}}{t} = \sqrt{\frac{R}{t}}$$

Example:

If 5000 counts were observed during a 4-minute counting period, what is the count rate at 95% confidence level?

n_S = 5000 counts

t_S = 4 minutes

$R_S = \frac{n}{t} = \frac{5000}{4} = 1250$ cpm

$\sigma_S = \sqrt{\frac{R_S}{t_S}} = \sqrt{\frac{1250}{4}} = \sqrt{312} = \pm 17.5.$

Using $2\ \sigma_S$ for ~ 95% C.L., $2\ \sigma_S = 2(\pm 17.5) = \pm 35$. Therefore, count rate, $R_S' = 1250 \pm 35$ cpm at 95% C.L.

<u>Percent of Relative Error</u>

Frequently the count rate is represented $\pm$ its relative or percent error. This is expressed:

$$R_S \pm \frac{\sigma_S}{R_S} \times 100\% \text{ (for 68\% C.L.)}$$

$$R_S \pm \frac{2\sigma_S}{R_S} \times 100\% \text{ (for 95\% C.L.).}$$

In the example:

$$\frac{2\sigma_S}{R_S} \text{ X } 100\% = \frac{2(17.5)}{1250} \text{ X } 100\% = 2.8\%.$$

Therefore:

$$R_S = 1250 \pm 2.8\% \text{ (at 95\% C.L.).}$$

Background Considerations

In general, there is always a background counting rate, R_B, which must be subtracted to yield the actual sample counting rate, R_S. For instance, if 128 cpm were the count rate (R_{S+B}), of a certain sample, and the background rate (R_B), was 72 cpm, the net sample count rate would be:

$$R_S = R_{S+B} - R_B = 128 - 72 = 56 \text{ cpm.}$$

What would be the uncertainty (error) in the net sample count rate? Is it 56 ÷ t? No! Since the theory of propagation of errors must be used, the error (σ_S) will be the square root of the sum of the squares of the individual errors.

$$\sigma_S = (\sigma_{S+B})^2 + (\sigma_B)^2$$

Example:

What is the error at a 95% C.L. for the problem if the counting times for both sample and background were 2 minutes?

R_{S+B} = 128 cpm

t_{S+B} = 2 minutes

$$\sigma_{S+B} = \frac{R_{S+B}}{t_{S+B}} = \frac{128}{2} = 64 = 8$$

$R_B = 72$ cpm

$t_B = 2$ minutes

$$\sigma_B = \frac{R_B}{t_B} = \frac{72}{2} = 36 = 6$$

$$\sigma_S = (\sigma_{S+B})^2 + (\sigma_B)^2 = (8)^2 + (6)^2 = 64 + 36 = 100 = 10$$

$R_S \pm 2\sigma_S = 56 \pm 2\ (10) = 56 \pm 20$ at 95% C.L.

A handy formula for net sample count-rate error is:

$$\sigma_S = \frac{R_{S+B}}{t_{S+B}} + \frac{R_B}{t_B}$$

Substituting these values:

$$\sigma_S = \frac{128}{2} + \frac{72}{2} = 64 + 36 = 100 = 10$$

<u>Background and Counting Times</u>

It is often not necessary to have a background counting time equal to the ssample counting time. Another useful formula to determine the most efficient use of counting times is:

$$\frac{t_{S+B}}{t_B} = \frac{R_{S+B}}{R_B}$$

Example:

If the sample counting rate were 400 cpm and the background 25 cpm, how much longer should the sample be counted than the background?

$$R_{S+B} = 400 \text{ cpm}$$

$$R_B = 25 \text{ cpm}$$

$$\frac{t_{S+B}}{t_B} = \frac{R_{S+B}}{R_B} = \frac{400}{25} = 16 = 4$$

$$t_{S\&B} = 4t_B$$

The sample should be counted 4 times as long as the background counting time. Thus, if 1 hour were available for the count, 12 minutes would be spent counting background and 48 minutes counting the sample.

This formula is utilized only for "one-shot" counting operations; for each sample, a separate sample count rate and background count rate should be made. In usual counting-room practice, however, it is not necessary to take a background count rate for every sample; background counts need be taken only 2 or 3 times a day. The formula is not applicable without modification.

PRACTICAL AIDS TO COMPUTATION

For a direct numerical approach, using the formulae discussed, a slide rule is usually accurate enough for squaring and taking square roots. Computation

may be considerably simplified by the use of Jarrett's nomographs, the most useful of which are reproduced on pages 115-118 of the Radiological Health Handbook (Rev. 1970). These cover counting rates from 1 to 100,000 cpm and counting times from 1 to 1,000 minutes, a range more than adequate to encompass the usual counting procedures. With a nomograph, a straight-edge is used to connect the observed count rate (cpm) with the duration of the count (minutes), and the error at the 90% or 95% C.L. is read off the intersection with the center line, on the left or right side respectively. In the example previously solved, the nomograph method gives a 95% C.L. error of ± 34.7 cpm for a sample which produced a count rate of 1250 cpm for 4 minutes. For background subtraction, the error in the background determination would be found in the same way, using the nomograph, and the individual errors from sample and background would be combined by squaring, adding the squares together, and extracting the square root.

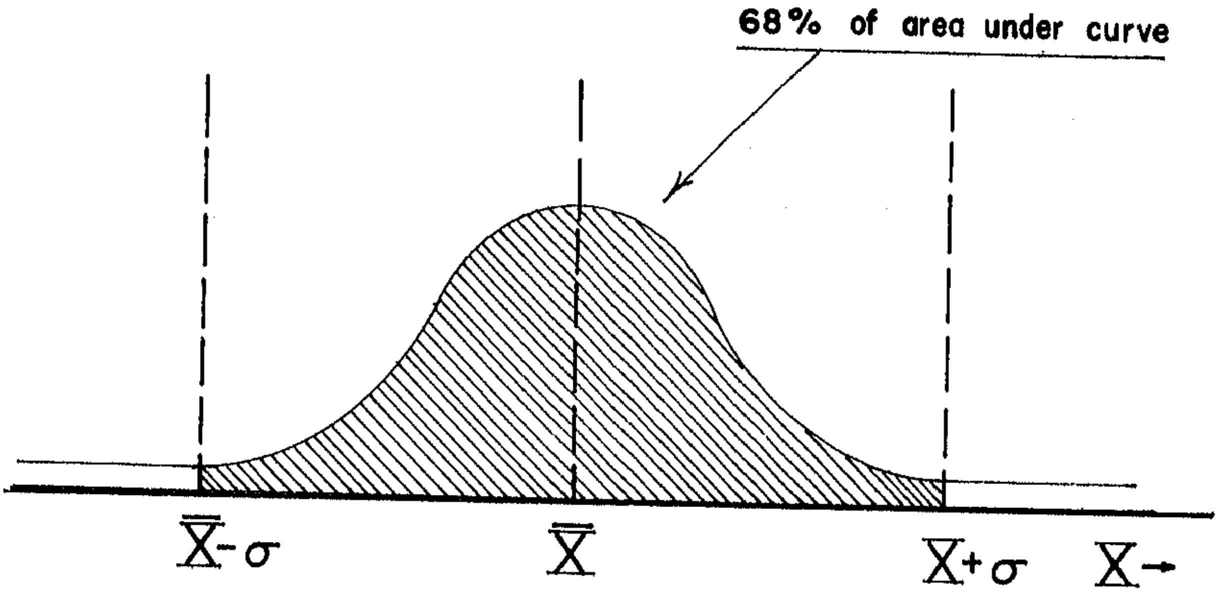

Figure 1. Normal Distribution

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SECTION 18

SAFE HANDLING OF RADIOISOTOPES

The use of radioactive sources in science and industry is increasing for a multitude of purposes. More than 40 companies supply radioactively "tagged" compounds and radiation sources from a stock or as special orders.

Technological advances will undoubtedly extend the uses of radioactive sources in many new and diversified areas in science and industry. As the number of people exposed to radioactive materials in their work increase and more people live in the proximity of facilities using radioactive materials, it is essential that the potential hazards to the population be given attention proportional to the degree and nature of the hazards.

Hazards in Handling Radioisotopes

Deposition of radioisotopes in the body may result from ingestion, inhalation, or absorption through the skin. Ingestion of radioisotopes may occur as an acute problem through the drinking of a contaminated liquid, but usually is caused by the accumulation of small amounts of radioactive material brought into the mouth by such means as cigarettes, food, or contaminated hands. Inhalation of radioisotopes in the form of gas, vapor, spray, or dust is particularly hazardous due to the large fraction of such contaminants that may be retained or absorbed by the lungs. It is difficult to expedite the natural rate of elimination of most isotopes once they have entered the body. For this reason, it is essential to avoid ingestion or inhalation of radioactive materials. Potentially exposed personnel should be tested periodically for such accumulations. When more than trace amounts of radioactive materials are handled, absorption of radioisotopes through an

open cut or even through the intact skin becomes a potential hazard. Recommended radiation protection standards for external and internal exposures and concentration guides (CG's) of radionuclides in air and in water may be found in ERDA Manual Chapter 0524.

Also of importance is the hazard of external radiation exposure. A fundmental requisite for safe handling of radioactive material and for protection against radiation exposure is the knowledge of radiation dose rate associated with the radioactive material being used.

Gamma ray dose rates in rads per hour per curie at one meter from several types of sources are listed in Table 1.

Dose rate in millirads per hour per millicurie at one foot may be obtained by multiplying the values of the dose rate in rads per hour per curie at one meter by 10.8.

TABLE 1

Gamma Ray Dose Rates in Rads Per Hour Per Curie at One Meter for Certain Radioisotopes.

ISOTOPES	HALF-LIFE	GAMMA RAY ENERGY (MeV)	DOSE RATE
^{22}Na	2.6 years	1.3	1.32
^{24}Na	15.0 hours	1.38, 2.76	1.89
^{51}Cr	27 days	0.32	0.02
^{54}Mn	300 days	0.84	0.49
^{59}Fe	45 days	1.1, 1.3	0.67
^{60}Co	5.3 years	1.17, 1.33	1.35
^{65}Zn	245 days	1.11	0.30
^{131}I	8.0 days	0.36 major, 0.08-0.72	0.225
^{132}I	2.3 hours	0.69 - 2.00	1.21
^{137}Cs	30 years	0.66	0.33
Ra (B + C)	--------	Filter through 0.5 mm Pb	0.83

Revised: January 1978

Once the dose rate from a radioactive source has been determined at a certain distance, the gamma dose rate at any other distance in air varies inversely as the square of the distance, according to the formula,

$$I_2 = \frac{I_1 \times (d_1)^2}{(d_2)^2}$$

Where I_1 is the exposure rate at a distance d_1 from the source and I_2 is the exposure rate at a distance d_2 from the source.

For example, if the exposure rate at one meter = 3 R/hr, the exposure rate at ten meters from the source is determined as follows:

$I_1 = 3$

$d_1 = 1$ meter

$d_2 = 10$ meters

$$I_2 = \frac{3 \times (1)^2}{(10)^2} = \frac{3}{100} = 0.03 \text{ R/hr or } 30 \text{ mR/hr}$$

If we know the exposure rate at one meter (3 R/hr) and desire to find the exposure rate at one centimeter, then by placing distances in the same units:

$I_1 = 3$ R/hr

$d_1 = 100$ cm

$d_2 = 1$ cm

$$I_2 = \frac{3 \times (100\text{cm})^2}{(1\text{cm})^2} = 3 \times 10^4 \text{ R/hr}$$

Revised: January 1978

It should be noted that inverse square relationships may not hold true with distances less than ten source diameters away from the source because of geometric considerations and that no allowances are made for air attenuation or scatter.

A rough rule of thumb for calculating exposure rate of a point source where the curie content of a single isotope source is known is:

6 CE = R/hr at one foot

where

C = curies of activity

E = total gamma energy per disintegration in MeV

In planning shielding to protect personnel from the radiations of gamma and neutron sources, the combined effect of gammas and neutrons must be considered. Lead is widely used for gamma shielding but is a poor absorber of neutrons and must be supplemented by paraffin, water, or other hydrogenous material. Approximately 30 mils of cadmium will absorb thermalized neutrons.

Methods and Controls for Handling Radioisotopes

The prevention of the spread of contamination is a primary design consideration for work spaces where radioactive materials are used. The most tightly sealed source may rupture or leak under the best of care, and it should be stored and used with this fact constantly in mind.

Areas in which radioactive materials are stored or used in wooden buildings should be constructed or reinforced concrete or heavy masonry to help prevent the release of radioactivity in the event the wooden structure is consumed by fire. Radiation areas should contain a minimum of furniture and

fittings. As few dust catchers as possible should exist such as hanging lamps, ledges, high shelves, or other relatively inaccessible regions where contamination could collect. Floors should be capable of supporting the weight of heavy shielding material. Floor covering should be resistant to chemicals, non-absorbent, easy to decontaminate and relatively simple to remove. Asphalt or rubber floor tiles, at least one-eighth inch thick, separated from a concrete sub-floor by a sheet of asphalt building paper and a layer of heavy "kraft" paper as a sealing material, have proven satisfactory for covering material. Periodic waxing and buffing will help keep the cracks between the tiles sealed. Walls should have non-porous, non-absorbent, smooth surfaces that are free from cracks and crevices. Corners where walls meet the ceiling and floor should be rounded to prevent dust accumulation and to simplify decontamination.

Ventilating air should flow from radioactively clean areas to areas that routinely contain radioactive materials, i.e., from "cold" to "hot" to "hotter" areas. This will assure that any radioactive substances in the air will be carried to areas of higher risk potential.

Liquids containing radioisotopes in concentrations less than the CG's may be emptied into "cold" drainage systems. Liquids containing radioisotopes in concentrations in excess of the CG's must be restricted to "hot" drainage systems, if available, or solidified for transportation to radioactive material disposal areas.

Work benches should be free from cracks, joints, sharp corners, or porous surfaces. Exposed surfaces should be chemical resistant and easy to decontaminate. It is recommended that bench tops be covered with impermeable

materials, such as stainless steel, lead, or plate glass. Strippable paint may suffice as a covering material when working only with substances of low activity. Stainless steel trays, lined with absorbent paper, are helpful in containing minor spills. During radiochemical operations, working surfaces should be protected by a layer of heavy absorbent paper backed with an impervious material such as oiled "kraft" paper or plastic sheeting. Contamination control is predicated on keeping the radioactive material in the smallest area at all times.

Stainless steel sinks are preferable to those of porcelainized cast iron or soapstone since they do not accumulate radioactive materials and when fabricated with rounded corners are easier to clean.

Operations with radioactive materials with low penetrating ability, such as alpha emitters and low-energy beta sources, can be carried out safely in glove or dry boxes. The glove box is designed to protect personnel from contact with the material and to prevent the spread of radioactive contamination by localizing the hazardous material (Figure 1). The glove box is a totally enclosed chamber constructed of Plexiglas or metal and is equipped with plate glass windows. Glove ports, fitted with air-tight rubber gauntlets, permit the worker to handle limited quantities of radioactive substances safely. Negative pressure maintains dusts or mists to the room, serves as an isolation contamination mechanism, and also prevents possible internal exposure hazards. At one end of the glove box is an air-lock through which equipment is introduced or removed. In this way, items may be placed in the box without having to open it directly to the outside.

Radiochemical hoods (Figure 2) are required where laboratory operations

are accompanied by the evolution of radioactive spatters, fumes, or gases. Hoods also serve as exhausts for the entire room ventilation system. National Bureau of Standards Handbook 42 prescribes that forced ventilation, which is capable of maintaining the room's radioactivity content below 10^{-9} microcuries per cubic centimeter, be provided for all hoods. In addition, it is also recommended that the linear velocity of air passing through the hood openings should be in the range of 100 to 150 feet per minute. A hood three feet wide, opened one foot at the cabinet front, reguires at least a 300 cubic feet per minute flow rate.

Special features of design and construction differentiate a radiochemical hood from a standard chemical hood. The base should be strong enough to support heavy shielding and massive enough to afford shielding from gamma radiation. The upper portion of the hood should be fabricated from metal, preferably stainless steel. The surface should be coated with strippable paint as an aid to decontamination. All working surfaces must be non-porous, heat resistant, and chemically inert. Small cup sinks located in the front section of the cabinet are recommended for their ease of cleaning and decontamination. Absorbent paper and stainless steel trays are recommended for spill control and containment. A room containing more than one hood should have a single switch to control all associated exhaust blowers. This serves to prevent a hood in operation from drawing contamination into the room from an inoperative hood. Blowers in conjunction with appropriate filters should be located on the roof rather than in the building to create a negative pressure and thereby prevent the escape of radioactive material from the exhaust system.

When radioactivity approaches curie levels, glove boxes and hoods do not offer sufficient protection against gamma rays, neutrons, and high-energy beta particles, and massive shielding becomes necessary for controlling external exposure to the worker. The most common structures for work with highly radioactive materials are caves and hot cells (Figure 3).

The cave, a four-walled enclosure with thick shielding, is designed for work with radioactive material up to curie amounts. At high levels the top of the cave must be shielded from "shine" due to scattering from the room ceiling and secondary radiation from air molecules above the cave. The completely enclosed structure is termed a "hot cell." The operating face of the cell may contain a large shielding window, mirrors or periscopes, master-slave manipulators, and various utility controls. The windows must offer adequate shielding against radiation as well as providing a clear view of the cell's interior. For this reason, windows are built of special composition laminated plate glass, high density lead glass, or are glass sided containers filled with high density liquid such as a saturated solution of zinc bromide. At very high radiation levels, periscopes or closed-circuit television becomes necessary when thick windows fail to satisfy the shielding requirement. Remote-control operations are conducted with maximum safety and accuracy through the use of master-slave manipulators. Each mechanical part of the master control has a duplicate part in the slave section. The operator's movements of the master section outside the cell are duplicated exactly by the slave section located in the cell. Master-slave manipulators may be mechanical or electrical. The electrical type has the greater load capacity. Both reproduce the seven fundamental hand motions (Figure 4): Forward-back, up-down, right-left, twist about

the three axes of rotation, and squeeze motion. Normally, these manipulators are placed in pairs, one for each hand. The mechanical variety enables the operator to carry out exacting tasks with greater dexterity than the electrical variety due to transmission of a suprisingly realistic sense of touch.

Radioactive sources used for relatively low-level calibration of instruments may be transferred from shielding containers with long-handled tongs or an electromagnet on the end of a long rod. Relatively high activity calibration sources can be pumped hydraulically from a shield-container through liquid-filled tubes for positioning. Sources are returned to the shielding container by reversing the direction of the pumping action. The pump is operated from a shielded remote control panel and sources of hundreds of curies may be transferred with minimum exposure to the operator.

Extreme personal cleanliness in handling radioisotopes is essential. The hands should be carefully washed at the end of every work period. Radioactive material must not be allowed to come in contact with the clothing. A laboratory coat, or other protective clothing, should be required in all areas where unsealed radioactive materials are being used. No edibles of any kind should be brought into the radiation areas, nor should they be touched until the hands are washed and found free of radioactive materials by a sensitive detecting device.

The work areas should be free from equipment and materials not required for the experiments at hand. After use, equipment should be decontaminated and stored in a controlled location.

The concept of "controlled areas" has found wide application in controlling the spread of radioactive contamination. A controlled area is any area specifically designated for working with contaminated materials and which can be physically segregated from non-contaminated areas. Room walls, ropes, or other barricades are frequently used to restrict access to such areas. Controlled areas are considered to be potentially contaminated, therefore criteria for protective clothing and equipment are set up based on the nature of the work normally performed, levels of activity expected, and types of radioisotopes in use. Access to non-controlled areas requires use of step-off pad procedures in order to assure that contamination is not spread to clean areas.

When the degree of contamination present in a controlled area is such that extensive protective clothing and equipment must be used, change stations and control points for radiation monitoring personnel may also be required. The use of air locks is also a valuable adjunct to other control measures when high airborne concentrations of radionuclides may be expected. Air locks are designed so that an air-pressure differential can be maintained between the lock and the controlled zone limiting the potential for spread of airborne contamination to clean areas or to other controlled areas.

Storage of Radioactive Materials

Radioactive material must be stored in an adequately shielded area which is fireproof and floodproof. The storage facility design is governed by the radiation levels of the material to be stored and the type and form (liquid, powder, etc.) of the material.

The containers in which radioactive materials are shipped make good storage units (Figure 5). A recommended precaution is to place the primary container in a secondary container of sufficient volume to contain the radioactive material should the primary container rupture or leak. A chemically inert absorbent placed between the two containers is recommended if the radioactive material is in a liquid state.

The storage area should be clearly labeled as a hazardous area and securely locked to prevent unauthorized removal of radioactive material. Radioactive materials entering and leaving the storage area should be logged in, proper labels affixed and logged out. Equipment on hand should include: remote handling equipment (Figure 6), lifting devices, decontamination equipment, and anti-contamination supplies.

Radioactive materials may be stored in a working area temporarily only if the radiation is shielded sufficiently to prevent overexposure to personnel working in the environment of the material eight hours per day.

Leak Testing of Radioactive Sources

Through rough handling, dropping, chemical action, or improper encapsulation a "sealed" source may develop a leak not apparent during visual examination, but capable of spreading contamination. Periodic surface swipes by using appropriate remote handling equipment can be made on the outside surface of the source, with subsequent counting of the swipes for alpha, beta, or gamma contamination, will allow detection of leaks. The source may be placed in a container of chloroform or acetone for 24 hours followed by evaporation of the solvent and counting of the residue for contamination. The "hot water" method of leak testing involves heating a container of water to slightly

below boiling. The source is placed in the water and if air bubbles rise out of the capsule, the source has a leak. The water may be evaporated and the residue counted for contamination as a further check. This procedure would not be used on sources which are vulnerable to the effects of heat. Radium sources may be provided with a cotton plug that can be removed and counted for any absorbed radon gas. A periodic leak test should be made on all sealed sources to prevent contamination due to leakage. A small leak may lead to a major contamination incident if not detected early and corrected.

Radioactive Material Transportation

The transportation of radioactive materials must comply with governmental regulations and be accomplished in a manner that minimizes exposure of personnel. This objective is met by adhering to the various governmental regulations and maintaining proper control during transfers of shipments. Health physics groups are responsible for keeping complete records on the routing and disposition of radioactive materials. Upon receipt of a container of radioactive materials, it is monitored to ascertain its radiological status. The shipment should be monitored externally with shielding intact and a minimum of two smears should be taken from the outer surface. After the shipment is opened, the unshielded primary container should be monitored and smear tested. If the radiation or contamination is in excess of established limits, a report must be filed with the Department of Transportation to comply with regulations. Transfer of materials should be from person to person, not from person to location or location to location. Containers should be constructed and shielded so that leakage or breakage cannot readily occur. The shielding must be adequate to protect personnel

during transit and while the containers are in storage. Radioactive material should not be hand carried when it can be transferred by truck or laboratory cart.

All packages containing radioactive materials for shipment must be labeled as specified in the regulations. Labels are described and illustrated in CFR 49 Part 173. Essentially the information on each label consists of: principal radioactive content, activity of contents, and radiation units (milliroentgens per hour at one meter) which determines transport index except for all shipments exempted from the stated labeling. (CFR 49 Part 173.391.)

More problems are involved in the transportation of radioactive material between installations than within an installation. Radiation must not be allowed to endanger transportation workers, loaders, or any persons who might be near the shipments. Also to be avoided is radiation damage to other materials, such as photographic film that might be placed in proximity to the shipments. As mentioned, shipments of radioactive materials are subject to federal and state regulations. CFR 49 Part 173 lists the significant applicable regulations concerning shipments.

A complete list of governmental regulations related to the interstate shipment of radioactive materials may be found in AEC Regulations Title 10, Federal Aviation Administration Regulations Title 14, and Department of Transportation Title 49. Health physics groups at installations using radioactive materials are responsible for determining that all out-going shipments of radioactive materials comply with the various regulations and are properly packaged and labeled.

Results of a comprehensive survey made by the AEC regarding shipment of radioactive materials by its contractors and licensees showed that: (a) over a 16-year period there had been no record of a radiation injury from such shipments, (b) small quantities (less than 20 curies of radioactive material) make up more than 80 percent of the shipments and (c) 58 percent of the shipments made by licensees are by air since most of the radioisotopes are short half-lived.

Waste Disposal

Safe disposal of radioactive wastes is based upon application of two basic principles:

1. Concentrate and Contain: Radioactive materials can be stored safely in permanently controlled reservations, but the volume of stored wastes would be prohibitively great if they were not first concentrated by calcination, evaporation, or compaction for long-term storage.

2. Dilute and Disperse: Wastes of appropriately low activity may be reduced to permissible levels for release by dilution in air or in waterways. Wherever materials are to be released to the environment, the amount of radioactivity that can safely be dispersed into that particular environment is determined quantitatively for each specific radionuclide.

When applying these principles, it is imperative that each case be evaluated individually taking into consideration the types of radionuclides involved, the physical form of the waste material, the levels and types of activity involved, and the options available for their disposal. Additionally, some

provision for auditing waste disposal standards and procedures should be maintained. Methods that have proved safe and effective for past disposal problems may be negated by changing conditions.

Most contaminated waste will, as a matter of course, probably be dispersed in an ERDA-approved waste disposal site. Such sites are maintained by ERDA Contractors at various locations in the United States. Additionally, the ERDA has licensed private companies to provide contaminated waste disposal services on a commercial basis. Most contaminated waste sites provide facilities for land burial of solid packaged wastes for low to moderate activity. High-level solid wastes may also be buried or concentrated in metal cans and dropped into steel-lined dry wells. Liquid wastes of low activity that may be unsuitable for disposal using the dilute and disperse concept may be solidified for land burial also. High-level liquid wastes are normally contained. Vast underground storage tanks of million-gallon capacity are available for high-level liquid waste disposal. One added advantage to this method is that such wastes are available for future reclamation of valuable radioisotopes.

SECTION 19

AIR SAMPLING TECHNIQUES

The purpose of any program of sampling airborne radioactive material is to determine the airborne concentration of radioactivity to which individuals may be exposed. Air sampling data are compared to the concentration guides (CG's) listed in ERDA Manual Chapter 0524, Standards for Radiation Protection. How well these values can be related to a hazard depends on certain variables: The accuracy of the sample volume; the accuracy of the counting equipment; and the accuracy of interpretation of the results.

In an emergency situation, such air concentrations may vary considerably. Suitable respiratory protection should be worn when entering an area where a release of radioactive materials is suspected. The use of such respiratory equipment should be continued until it is fully established that further work will not generate airborne contamination.

Collection of Airborne Particulates

The collection of airborne particulates will normally be performed at the same time dose and dose rate information is determined at an incident site. The hardware available for particulate air sampling may vary from very simple mechanisms, such as a lapel sampler, to a complex device that collects, counts, and calculates the concentration. Almost any type of air mover can be used if the flow rate or volume displacement can be measured or calculated. For instance, for want of a better device, an automobile tire pump with a filter head could be used. Measurement or calculation of the volume of the pump cylinder, multiplied by the number of pump strokes, would give the volume of the sample.

Other innovations to accommodate air sampling in locations where line electrical power is not available include battery-operated samplers, vacuum bottles, and air samplers operated from the intake manifold or exhaust systems of automobile engines. For intake manifold samplers, direct in-line sampling is used, although this system tends to choke the engine excessively. Direct in-line exhaust system sampling is not acceptable because of the problem of clogging the filter with combustion gases and particulates. However, by utilizing aspirators with either the intake or exhaust, satisfactory samples can be obtained. The flow rates will be reduced, but the engine performance will be greatly improved.

Gas-driven vacuum pumps provide very good sources of vacuum. Gas-driven compressors, utilizing aspirators, as well as such simple devices as a garden hose, when coupled with an aspirator, will provide a suitable source of vacuum.

Samplers such as the Staplex High Volume Air Sampler or the Hurricane Air Sampler are well-suited for use with either impaction or filter-type collectors. One model of the Staplex Air Sampler operates on the battery power provided from a 12-volt, D.C. electrical system. Filter Queen Vacuum, sometimes referred to as "Queenie," Motoaire vacuum pumps, and similar pumps of moderate flow rate are also commonly used.

Calibration of these commercial samplers is normally performed using such devices as orifice meters, anemometers, rotometers, and venturi meters. For the general field situation, measuring the pressure drop across the filter probably allows the greatest ease of determining flow rates from uncertain power sources. When possible, the sampling equipment should be calibrated

with one of the better standards, such as the orifice meter, anemometer, venturi, or rotameter. Calibration may be based upon pressure drop, so that the reading of a simple water vacuum gauge installed downstream of the filter is directly related to the flow rate.

Filter media common to particulate air sampling include Hollingsworth and Vose type HV-70 filter (a cellulose-asbestos filter of 18 mil thickness), CWS type 6, a similar filter, and Whatman No. 41, a common laboratory ashless filter paper. Glass fiber filters and membrane filters, such as Millipore filter, are also used. The choice of filter medium must weigh the importance and advantage of collecting small particles against the disadvantages of high pressure drop across the filter medium and the resultant low flow rates. Availability of analytical chemistry techniques should also be considered. The collection efficiency of the several filter media are stated by the manufacturers, but considerable variation from these stated values has often been found in actual field sampling conditions. This variation is usually a function of flow rate; HV-70 and CWS type 6 are generally regarded to be very good down to a particle size of 1 micrometer; Whatman No. 41 is generally considered good down to 1 micrometer; and membrane filters and glass fiber filters are effective below 0.1 micrometer.

Collection heads on which the filters are mounted vary from 3/4-inch in diameter to about 8" x 10" rectangles. One important point should be kept in mind when installing collection heads: the efficiency of the filter medium is lost if a tight seal around the edges of the filter is not assured.

It is frequently quite important to know the size of the particles being collected to determine respirability. Unfortunately, accurate particle

size analysis is very difficult and there is no satisfactory field method for making accurate determinations. Therefore, airborne contamination should be assumed to be in the respirable range.

Determination of Concentration

Variables which determine the accuracy of air sample results are the type of sampling equipment used and the size of the sample taken. Precise measurement of air flowing through a pump or pipe or filter is complicated by such variables as temperature, barometric pressure, friction, and leakage.

The sum of these errors can be offset, in part, by increasing the total volume of the sample. Assuming a fixed flow rate, increasing the sampling time will improve the accuracy of the sample in proportion to the square root of the time, assuming that the contaminant is present for the entire time. Increasing the sampling time presents no real difficulty when the interest is in long-term average concentrations, precision, or in detection of very low levels of airborne contaminants. However, longer sampling times may be undesirable when the interest is associated with short-term peaks or prompt evaluation of air contamination. An example of an air sample calculation, assuming 50% counting geometry, is as follows:

$$dpm/m^3 = \frac{cpm \times A_f}{0.5 \times m^3 \times F \times E_f \times E_c \times A_c}$$

where:

dpm/m^3	=	Disintegrations per minute found in one cubic meter of air
cpm	=	Counts per minute indicated by instrument
cpm/0.5	=	dpm (cpm corrected for instrument geometry)

A_f	=	Area of filter used (any units)
A_c	=	Area of filter actually counted by the instrument (same units as A_f)
F	=	Alpha absorption factor for filter used (from manufacturer's specifications)
E_f	=	Collection efficiency of filter used (from manufacturer's specifications)
m^3	=	Total volume of sampled air in cubic meters
E_c	=	Efficiency of counting instrument

The background radioactivity should be subtracted from the calculated concentration to compare to protection standards.

Due to naturally occuring radon and thoron gases in the atmosphere, any air sample taken will show a significant activity from the particulate daughters of these gases. Radon daughters, whose longest half-life is 30 minutes, may be considered completely decayed after 4 hours. Thoron daughters, whose longest half-life is 10.6 hours, will be decayed away in 3 days after completion of the sampling. Therefore, in order to determine the true activity of an air sample, one must be aware of the contribution of the radon and thoron daughters to the total activity of the sample.

It is necessary to exercise careful judgment in selecting sampling locations to assure the most representative sample possible. Several small, battery-operated air samplers should be available that can be worn on one's person. Evaluation of such a sample requires good judgment, based on a careful analysis of the work situation and recognition of exactly what information is supplied by the sample.

Collection of Gases

An important and frequently difficult part of an air sampling program is the collection and analysis of radioactive gases.

In typical reactor and weapons testing operations, radioactive iodine is of great importance. Iodine can be sampled by passing the suspect air through caustic solutions or charcoal. The usual air movers, such as a vacuum line or pump, are employed to draw the gas sample through the collector. Where acid concentrations are low, the caustic "scrubber" contains a solution 0.05 N NaOH and 0.05 N Na_2CO_3. For higher acid concentrations, more caustic is added. Separations plant stack gases are sampled using 0.2 N NaOH. 18 N NaOH has been used to sample gases directly from a fuel element dissolver vessel.

Analysis of the collected radioiodine can be made using either a gamma-ray spectrometric measurement of the solution or by means of wet chemistry. This latter method involves the addition of $AgNO_3$, precipitation of AgI, filtration, and beta counting the precipitate.

Charcoal cartridges have been used for iodine sampling in recent years. Charcoal has nearly 100% collection efficiency for elemental iodine under ideal laboratory conditions, but great care must be exercised in field applications. Factors causing loss of efficiency during field use include poorly constructed cartridges containing voids in the charcoal and an excessive sampling flow rate. Both of these can cause channeling of the gas through the cartridge without sufficient contact between the charcoal and the iodine. The chemical form of the iodine also affects the efficiency of charcoal collection. For example, organic iodines can be collected with

high efficiency by using a cartridge of activated charcoal impregnated with KI and I_2. Another consideration is high humidity and/or acid concentrations which might leach previously collected iodine from the charcoal. The amount of interference from these various factors can only be determined empirically.

A method for measuring tritium oxide in air consists of drawing a sample through a cylindrical bed of desiccant material such as silica gel or Drierite, where moisture, with any accompanying tritium oxide, is collected. The desiccant cylinder is taken to the laboratory where the collected moisture is driven off by heat and recondensed. The liquid water can then be analyzed for tritium content using several different counting techniques such as liquid scintillation counting or by gas flow counters. Hydrogen generated from the liquid can be directly placed in an ion chamber as another means of evaluation. From the counting results (expressed in μCi tritium per gram or cm^3 of water) and humidity data on the gas sampled (expressed as grams of H_2O per cc of air), the microcuries of tritium per cubic centimeter of air can be calculated. This method is limited by the capacity of the desiccant used. Saturation of the desiccant drastically reduces the value of the sample.

The most common method of tritium detection in emergency situations is with a portable integrating ionization chamber referred to as a "sniffer". It is a continuous air monitor containing an electrometer circuit that measures current from ionized particles in the air. A precipitation chamber is used to remove free ions from the air before the sample enters the detector chamber. Since the instrument is very sensitive, it can be made to alarm in the presence of gamma radiation or in heavy concentrations of smoke.

Noble gases such as argon-41, krypton-85, and xenon-133 are difficult to measure at low concentrations. Because they are chemically inert, one of the best ways to concentrate a sample of noble gases is with a cryogenic trap or a charcoal sampler maintained at a very low temperature. They can also be monitored by passing the gas sample through a continuous flow ionization chamber, such as a Kanne chamber. Their concentration must be high enough and precautions must be taken to remove other interfering radionuclides and excessive moisture.

A one-liter ionization chamber, such as might be used as a tritium sampler, can be used to good advantage to monitor noble gases if only single nuclides or mixtures of known composition are present. A filter and/or charcoal trap installed ahead of the chamber intake will remove interfering particulates or halogen gases. This method has been used successfully to measure ^{85}Kr concentrations down to approximately 2×10^{-7} μCi/cc or a few percent of the CG.

Large volume, high concentration clouds of noble gases can be measured with portable radiation detection instruments. From these measurements a direct estimate of the hazard can be obtained since the MPC is established on the basis of immersion dose. Estimates of concentrations can also be made if an "infinite" of "1/2 infinite" cloud can be assumed. Under these conditions, one assumes that all energy emitted is absorbed. The known disintegration energies of the noble gas is then employed to calculate the activity present.

Air Sampling In Emergency Situations

Upon arrival at the radiation incident site, one may be faced with almost any situation. Airborne contaminants may be in the form of a cloud of

radioactive noble gases which contribute essentially to an immersion dose. Contaminants may be in the form of water droplets from condensing steam of a ruptured vessel of radioactive material as a result of high temperature pressure. Gross quantities of particulate contamination could be spread over a large area; winds will contribute to the problem by resuspending particulates which have been deposited as fallout.

A person who has inhaled contaminated air may become the source of airborne contaminants as he exhales. If his clothing or body is grossly contaminated with loose dusty material, this also can become airborne. Therefore, an experienced monitor will never step across the line that demarcates the contaminated area from the clean area (Hot Line) until he is sure that he will not spread contamination.

Placement of air samplers upon arrival at an incident scene, and the proper recording of data received from them are important factors in the assessment of any hazardous condition due to airborne radioactivity. Usually, an air sampler is placed approximately 500 meters upwind of the accident scene in a clean area to obtain an indication of background radioactivity. A sampling time of approximately 30 minutes will allow this determination.

An additional air sampler is placed at the Hot Line and is operated continuously and monitored periodically during team operations. A third air sampler is placed approximately 25 meters downwind from the accident and is also operated continuously and monitored periodically. Samplers should be placed in all nearby populated areas, particularly those downwind (Table 1). This air sampler should be operated until there is no danger of airborne contamination at that point. The locations for sampling should be changed as wind directions change.

When recording air sample data, the following information should be included:

1. Location of sampler
2. Average flow rate
3. Sampling time and date
4. Type of filter
5. Wind direction and weather conditions

When applying air sampling data to protection standards, any background radioactivity should be subtracted from the calculated airborne contamination. Respiratory protection guidelines for airborne contamination are shown in Table 2.

Occasionally, an incident will result in the release of either large or very small amounts of airborne materials. These opposing conditions lend themselves to a convenient "go - no go" evaluation of the need for respiratory protection. For intermediate amounts, although there are specific external dose limits established for emergency situations, there are no known statements in authoritative literature concerning relaxation of CG or MPBB values for emergency work.

For field evaluation, a rough estimate of the airborne concentration can be made utilizing portable survey instruments and an appropriate air sample filter. The probe is placed in contact with the filter media, across the diameter, so that the maximum geometry factor is provided. For the E-500B GM probe with open window, assume a 2 percent geometry factor. Assume 50 percent geometry factor for alpha counters. The indicated cpm is then converted to dpm. Finally, utilizing those parameters available in the preceding formula, a rough estimate of the dpm/m^3 can be made.

TABLE 1

AIR SAMPLER PLACEMENT

WIND VELOCITY		DOWNWIND DISTANCE	
MPH	KNOTS	METERS	YARDS
6-10	5-9	1050	1148
11-15	10-13	1550	1695
16-20	14-17	2050	2242
>20	>17	2550	2789

TABLE 2

RESPIRATORY PROTECTION GUIDELINES FOR AIRBORNE CONTAMINATION

EXPOSURE LEVEL	RESPIRATORY PROTECTION
0 to 100 dpm/m^3 (alpha)	No respiratory protection for short-term exposure.
4 X 10^{-11} μCi/cc beta, gamma	Respiratory protection required.
100 to 10,000 dpm/m^3 (alpha)	High-filtration full face respirator at least 99.9 percent effective.
Greater than above levels	Self-contained breathing apparatus.

SECTION 20

AREA MONITORING/CONTROL

Techniques of area control are essentially the same whether the assignment is a routine, pre-planned operation, or an emergency incident such as a rail, air or highway crash, a processing plant mishap, or a reactor excursion.

The main difference between routine and emergency radiological operations is the amount of pressure upon those directing and controlling. To the usual confusion and excitement of any untoward event are added the fear and misunderstanding which still surround anything with atomic energy, as far as the general public is concerned.

Just as in a routine area control operation, planning is the important first step in protecting the public and possibly national security at the scene of an accident involving radioactive material. At least partial information will probably have been supplied by federal agencies and/or civil authorities to emergency response team members prior to their arrival on the scene, and this early information should be used, along with initial data impressions upon arrival, to make tentative plans for area control.

A wide variety of factors must be considered before demarcating the control, or exclusion area. Radiation levels may or may not be of primary concern depending upon what exactly is involved, but the decision making process should include consideration of gamma exposure rates, possible nuclear criticality, and spread of contaminants as diverse as tritium, alpha-emitting nuclides, and chemical toxicants.

If the incident involves a nuclear device, then there is a possibility of explosive hazards as well as fire. Many metals (uranium, plutonium, lithium),

frequently associated with nuclear industry are pyrophoric under some conditions and can burn with great intensity. Fire fighting methods themselves can add to hazards such as covering a thermally hot nuclear device with a blanket of foam, thus insulating it and aiding heat build-up, or by spreading contamination through flooding an accident scene with large quantities of water. Small pieces of unstable high explosive could be scattered around the scene following an accident involving a device in which the device case was ruptured. Foam could make detection and recognition of these pieces difficult. Other hazardous materials that could present problems if present include lead and beryllium, both particularly problematical as airborne fumes or dusts.

Delineation of a control area, then, is not determined solely by gamma meter readings. Input of data from many variables must be considered. Included in these variables are exposure rates, radioactive contamination (alpha, beta, gamma), airborne radioactivity, toxic materials (lead, beryllium, various gases), explosion, fire, national security, weather conditions, location, geographic/topographic features, population density, actions previously taken by those already on the scene, etc.

Collection and analysis of air, soil, and water samples from both within and outside of the exclusion area can prove to be invaluable for documentation of actual conditions at the scene. Data from these samples can be used to estimate exposures and contamination levels and to prove the effectiveness of control and decontamination efforts.

Reduced to its primary objective, the purpose of area control is the prevention of radioactive contamination and radiation exposure. Following initial data input as discusses above, this can be accomplished in four steps:

1. Initial monitoring upon arrival to determine the extent of contamination spread and apparent radiation exposure levels.

   This should properly be done as expeditiously and as unobtrusively as possible. There can be occasions when it would be ethically correct to chance contaminating one's street clothing rather than risk further alarming already nervous bystanders. Two-man teams--one recording, the other reading meter indications, are an efficient means of accomplishing this initial survey.

   There are primarily two methods of survey. Figure 1 shows a radial survey plot, in which intensity levels are found as they intersect the 8 cardinal points of the compass and are plotted accordingly on any available map. Such readings could be in counts/minute or mR/hr, whatever is applicable. Such a plot of gamma intensitites would delineate isodose contours (1 R/hr, 100mR/hr, 10 mR/hr, etc), and would provide meaningful historic data in addition to being an aid to communication with other concerned agencies and personnel. It might be desirable to establish a field dose rate decay study by placing location markers at some fixed points within the radiation field and noting the readings periodically. These readings can then be plotted as seen in Figure 2.

2. <u>Isolation of the involved area through the use of barricades, rope fences, etc.</u>

Almost anything that can help provide a visual and physical barrier can be utilized--police and fire department barricades, radiation ribbon from the ERAT kits, hardware store rope, etc. In placing the barricades, consideration should be given to present and possible future weather and wind conditions. It is better to enclose a large area and reduce it later than to enclose an area too small to allow for conditions like windspread or water run-off. Ideally, the barrier line should be placed so that at any point along it the radiation levels are at or very near normal background for the location.

It is not necessary to complete the initial survey before setting up the control barricades. As time and manpower availability permit, it might also be desirable to demarcate intensity lines by placing barricades with signs indicating 10 mR/hr, 100 mR/hr, etc., at appropriate points.

3. <u>Anti-contamination procedures to minimize the spread of conatmination.</u>

The basic anti-contamination procedure is to barricade and isolate as noted above. Further action is possible, however, and might include some provision for temporarily fixing existing contamination in place. Depending upon the situation, water, foam, or oil could aid in reducing contamination spread. Earlier mentioned precautions concerning nuclear material pyrophoricity, and high explosives should be followed. If there is to be a decontamination effort using large quantities of water, then the water run-off must be contained. At times it may be possible to establish secondary barricades and hot lines within the help control zones of high contamination.

4. <u>Hot line procedures to control contamination spread during team operations.</u>

One point should be established through which all traffic into and from the exclusion area must flow. The hot line should be uphill and downwind from the scene of the incident. Personnel entering the area must be logged and allowed access only after ascertaining that proper protective clothing and equipment are being utilized. Although it is not properly a function of the radiation safety group to control access in the operational or security sense, close coordination with those in authority must be maintained. Traffic should be kept to an absolute. minimum. Vehicles and equipment responding to the emergency should be tagged "contaminated" as they enter the area. Small items of equipment (such as radiation meters) can be protected from contamination by covering them with plastic before they are taken into the area. Two members should be designated as "hot line monitors" and assigned to exclusive duty at that station. Every vehicle, every piece of equipment, every item of gear, and every individual exiting the exclusion area must be painstakingly monitored to control the spread of contamination.

Area control is not a science, but an art. Known facts such as radiation readings and physcal evidence must be integrated with estimates such as wind and weather conditions when deciding where to place barricades. Each accident scene will be different and there are no upper or lower limits to the possible magnitude of the involved area. Emergency response personnel must be knowledgable, well trained, and able to remain calm and firm under the pressures generated in an emergency

situation. Assignments must be accomplished in a rapid but methodical manner in order to minimize the spread of contamination.

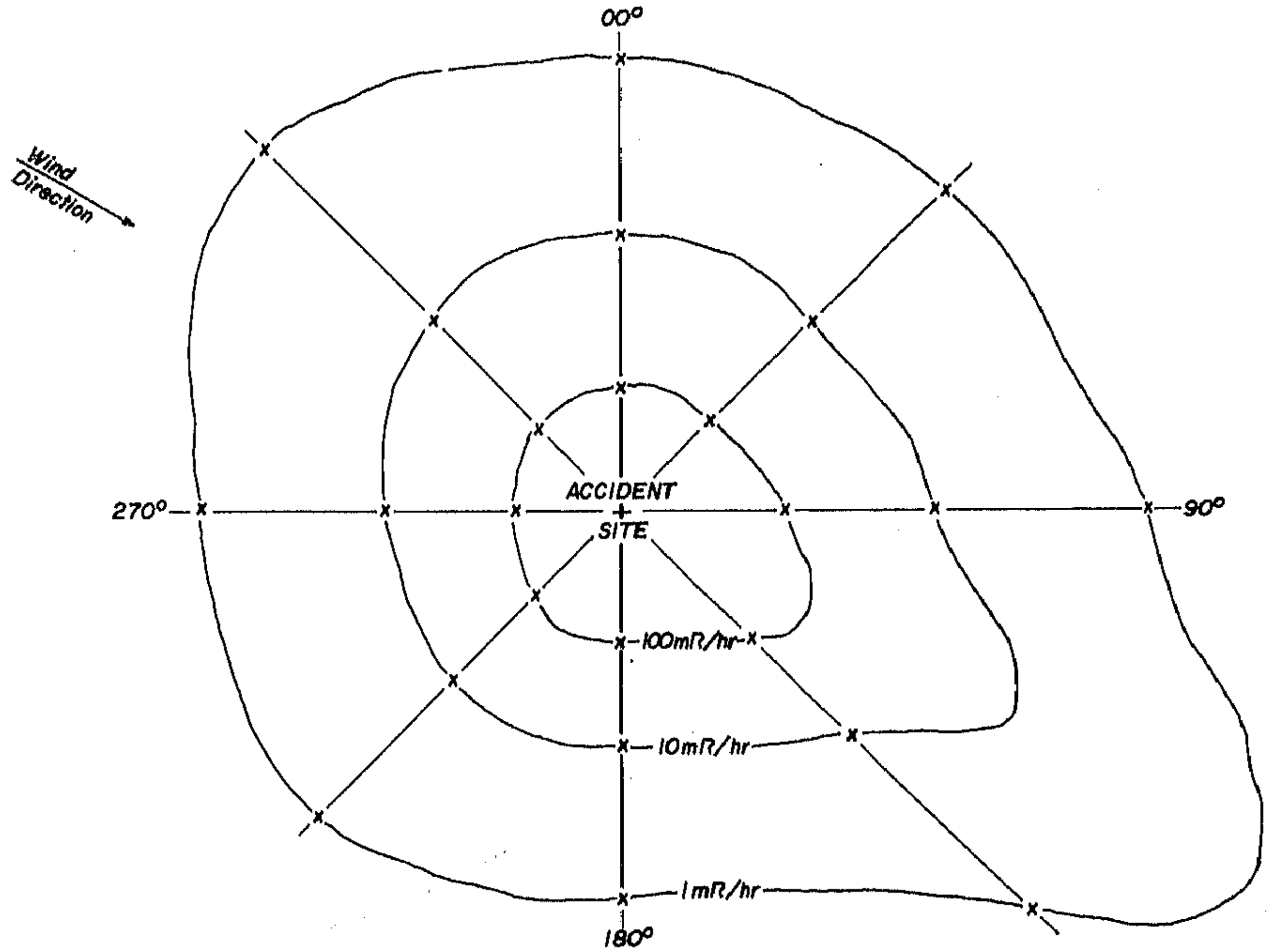

Figure 1
RADIAL SURVEY PLOT

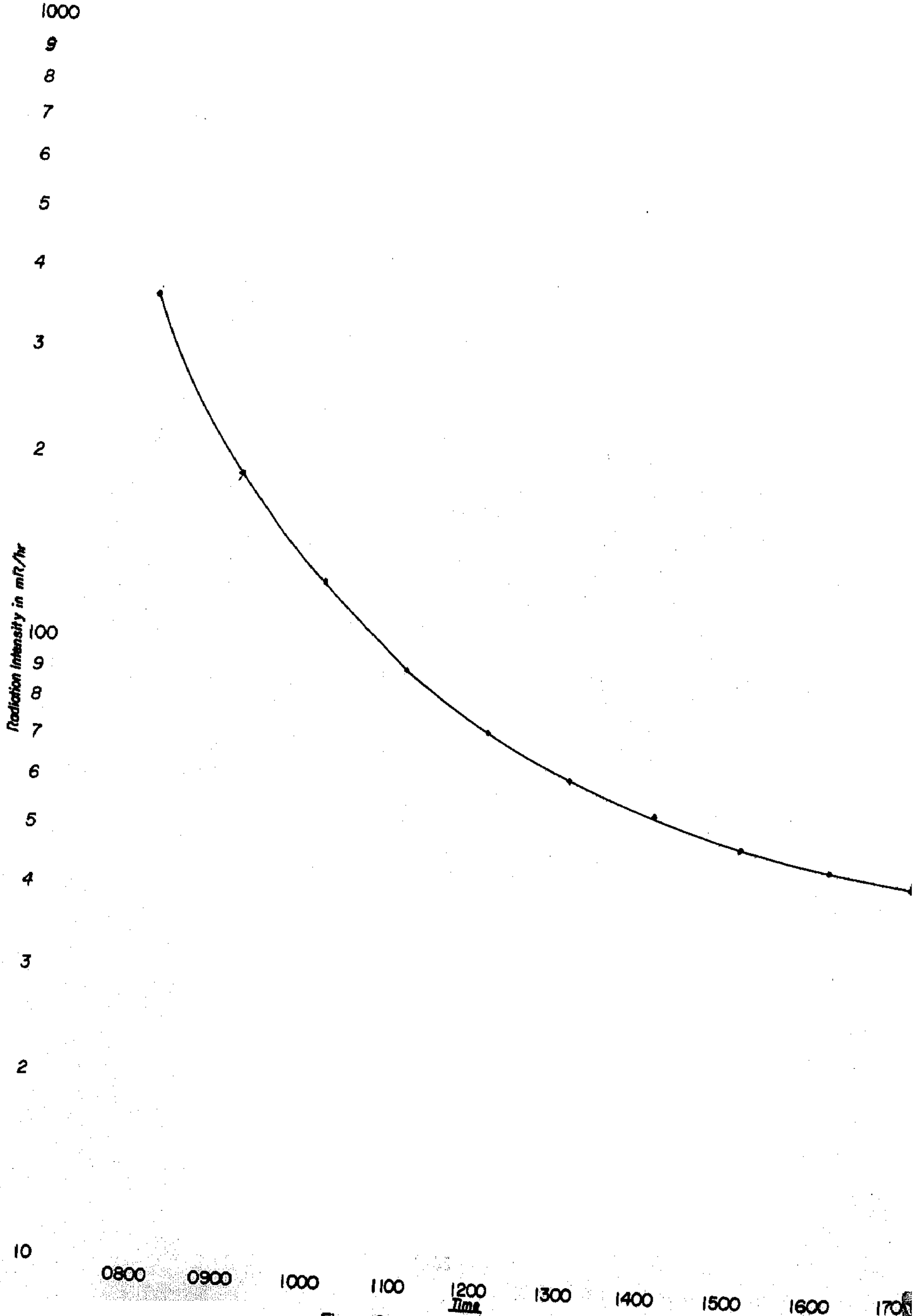

Figure 2 DECAY PLOT 20.8

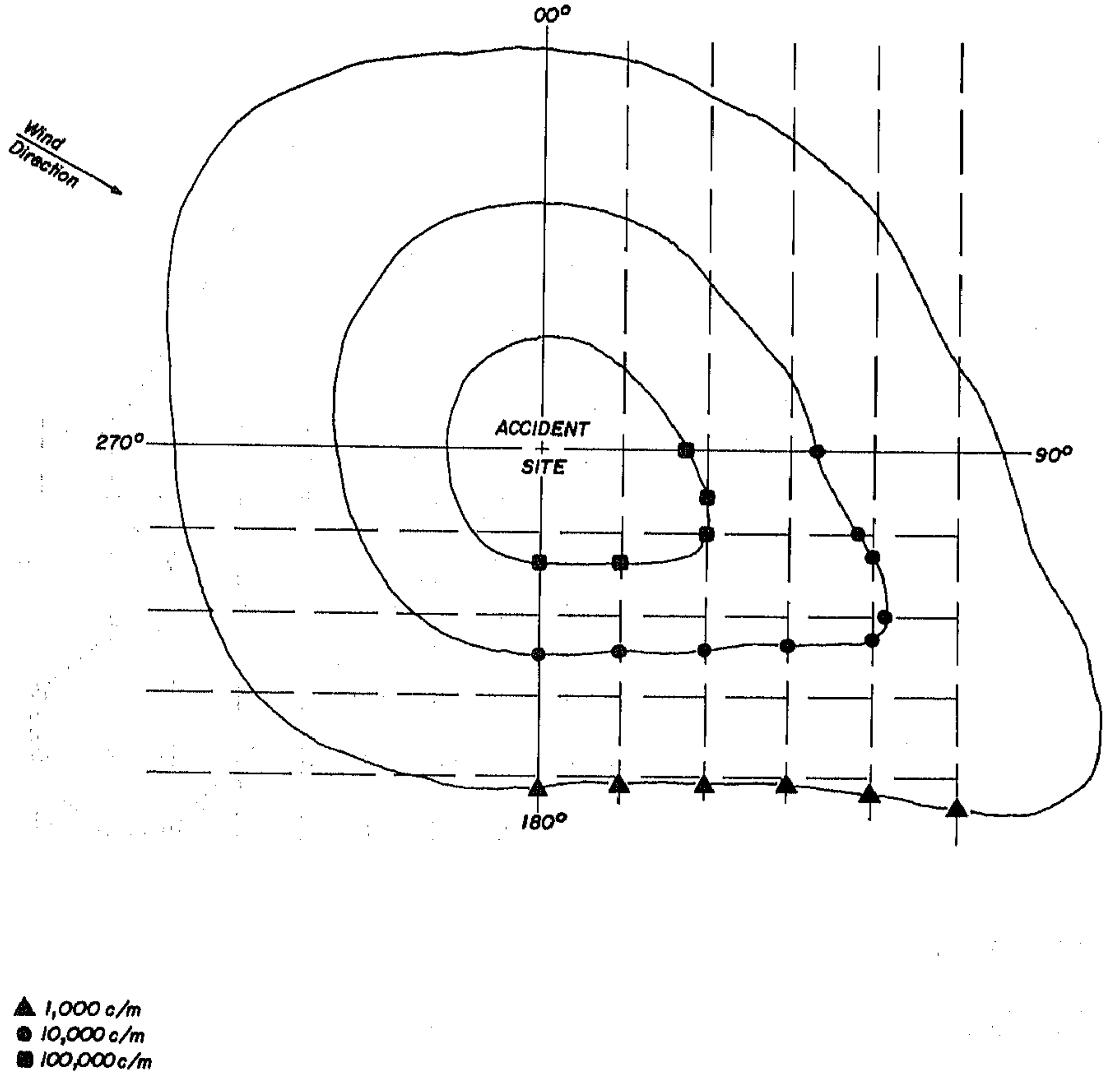

Figure 3

GRID SURVEY PLOT

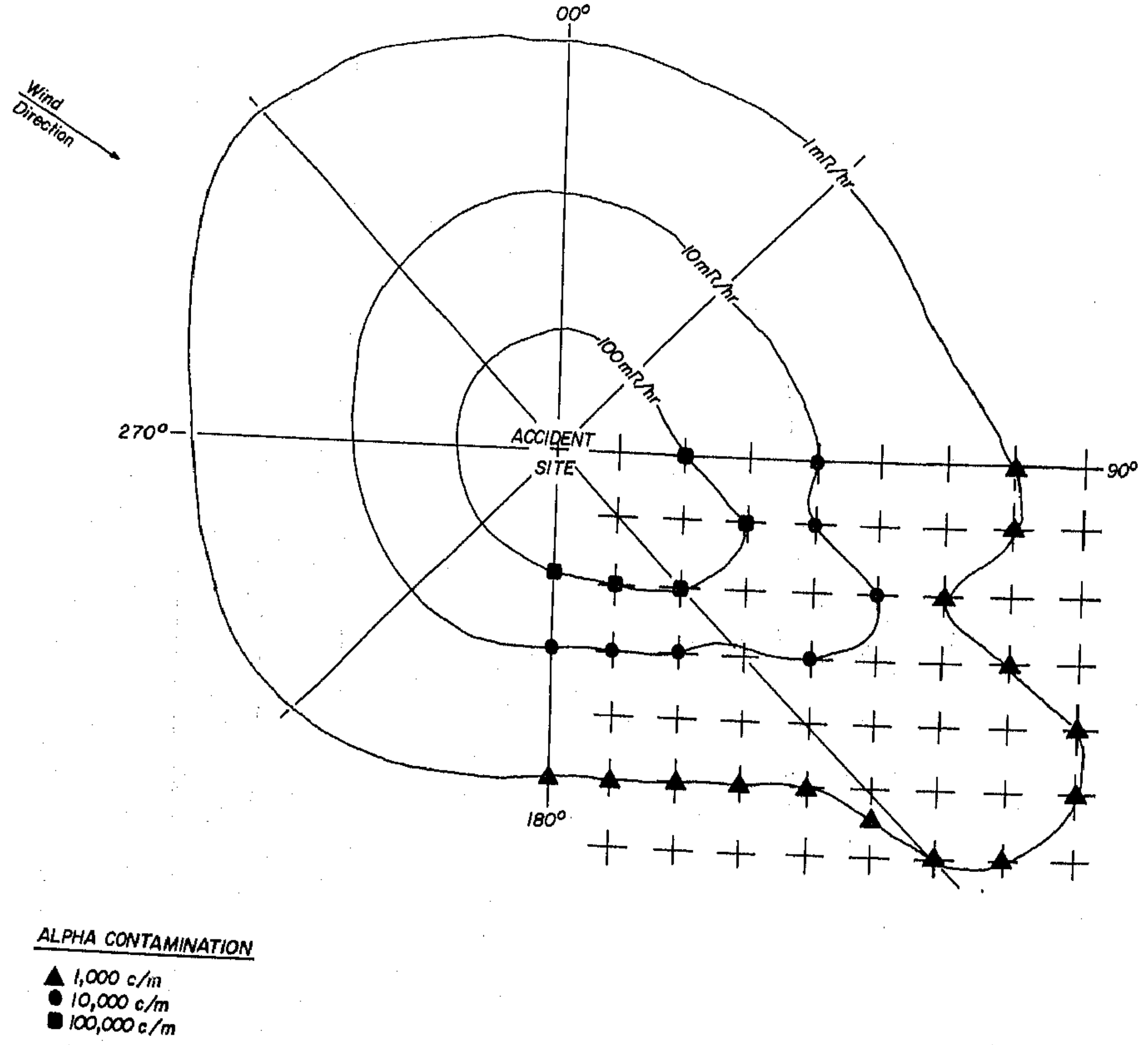

Figure 4

RADIAL AND GRID PLOT COMBINED

RADIATION MONITOR'S DATA SHEET

TEAM IDENTIFICATION__________ MONITOR______DATE ______

APPROXIMATE TEMPERATURE________ WIND: Velocity________ Direction________

SURFACE COMPOSITION__________ SURFACE CONDITION__________

WEATHER__________

Time	Item or Location	Reading	Type ($\alpha\beta\gamma n$)	Remarks

Figure 5

SUGGESTED FORMAT FOR RECORDING OF RADIATION SURVEY INFORMATION

SECTION 21

NONRADIOLOGICAL HAZARDS ASSOICATED WITH RADIATION ACCIDENTS

Introduction: Nonradiological hazards associated with radiation accidents will be determined largely by the environments in which the accidents occur. This chapter provides some basic information which is necessary in making wise decisions in those situations. It is not intended to supplant the advice of experienced professionals; rather it should enable the layman to confidently manage the situation until expert help and advice is available. Integration of the chapter material with an accident mangement technique such as outlined below should minimize the possibility of aggravation of an accident situation.

Think orderly and clearly
Evaluate the hazard
Remember the safety of team members
Protect personnel and property
Stabilize conditions whenever possible
Limit further damage
Eliminate the hazard as soon as possible
Use proper clean-up and disposal procedures

Specific information for managing a particular emergency may be obtained from some of the following sources:

1. CHEMTREC. Sponsored by the Manufacturing Chemist Association. Their telephones are manned 24 hours per day. They are prepared to furnish information on hazardous chemicals; they also have access to other

information systems. Telephone: 800-424-9300. Address: Manufacturing Chemists Association, 1825 Connecticut Avenue N.W., Washington DC 20009.

2. Local Poison Control Centers.

3. The Center for Disease Control which is located in Atlanta, Georgia, can provide information on biologic agents and toxins.

4. The manager of the carrier if a common carrier is involved.

5. Bills of lading.

6. Nearby Universities, Industries, Fire and Police Departments, Military installations, and Local and Federal government agencies.

If you are not familiar with the terminology of Industrial Hygiene, you may find it easier to refer to the glossary of terms before studying this chapter.

NONRADIOLIGICAL HAZARDS

Many substances or agents other than radioactive materials are in the environment during or following a radiation accident. These may include chemical vapors and gases, decomposition products or complex materials, metal fumes or smoke, dust and other particulate matter, physical agents like excessive heat and noise, etc. It is quite possible that some of these chemical substances may be hazardous to members of the radiological emergency teams.

Many extremely toxic compounds are used in industry completely without hazard because precautions are taken to limit actual contact with them to amounts

which will not cause injury. The toxicity of a substance is its inherent capacity to produce injury whereas the hazard is the probability or likelihood of injury resulting from the specific exposure to the substance. The physical and chemical properties determine how much enters the body, by what route, how frequently and for how long--all of which can be described simply as the exposure. Thus it is completely possible to have a high degree of hazard associated with a low order of toxicity and a low degree of hazard associated with a high order of toxicity depending on the exposure.

Threshold Limit Values - TLV's (Table 1)

1. The American Conference of Governmental Industrial Hygienists has established TLV's which refer to the airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed--day after day--without adverse effect. Because of wide variation in individual susceptibility, exposure of an occasional individual at or even below the TLV may not prevent discomfort, aggravation of a pre-existing condition, or occupational illness. Threshold limits should be used as guides in the control of health hazards and should not be regarded as fine lines between safe and dangerous concentrations.

2. There are three categories of Threshold Limit Values (TLV's) as follows:

   a. Threshold Limit Value - Time Weighted Average (TLV-TWA). The time weighted average concentration for a normal 8-hour workday or 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

b. Threshold Limit Value - Short Term Exposure Limit (TLV-STEL). The maximal concentration to which workers can be exposed for a period up to 15 minutes continuously without suffering from 1) intolerable irritation, 2) chronic or irreversible tissue change, or 3) narcosis of sufficient degree to increase accident proneness, impair self-rescue, or materially reduce work efficiency, provided that no more than four excursions per day are permitted, with at least 60 minutes between exposure periods, and provided that the daily TLV-TWA also is not exceeded. The STEL should be considered a maximal allowable concentration, or absolute ceiling, not to be exceeded at any time during the 15-minute excursion period.

c. Threshold Limit Value - Ceiling (TLV-C). The concentration should not be exceeded even instantaneously.

For some substanced, e.g., irritant gases, only one category, the TLV-C may be relevant. For other substances, either two or three categories may be relevant, depending upon their pphysiologic action. It is important to observe that if any one of these three TLV's is exceeded, a potential hazard from that substance is presumed to exist.

Emergency Exposure Limits - EEL's (Table 1)

1. The National Research Council of the National Academy of Sciences established EEL's which are a concentration of contaminants that can be tolerated without adversely affecting health but not necessarily without acute discomfort or other evidence of irritation or intoxication.

They are intended to give guidance in the management of single, brief exposures to airborne contaminants in the environment.

2. EEL's cannot be used like TLV's as guides in the maintenance of hygienic working environments but rather as guidance in advance planning for the management of emergencies. They are peak values which should not be exceeded except in circumstances where the risk is justifiable in order to prevent a still more serious event.

<u>Other</u>

1. TLV's and EEL's are provided, depending on availability, for many of the substances discussed in this chapter. Unfortunately the airborne concentrations of all the gases, vapors, fumes, mists, etc., cannot be easily determined by a simple so-called field method or instrument. Consequently, it may be necessary to obtain samples of the atmospheric contamination for laboratory analyses. These samples may be collected on silica gel, in an impinger or bubbler, in an evacuated cylinder or flask, in an inert plastic bag, in an electrostatic or thermal precipitator, on filter paper, etc. Appropriate references should be consulted for the detailed chemical analyses available for suspected contaminants. These samples are of no value for preventing or controlling exposures, but may be useful for the subsequent diagnosis and treatment of illness, decomentation, etc.

2. Physical agents, such as noise and excessive heat, may also be present following certain types of accidents. For long periods of exposure, it is advisable to wear some type of hearing protection, e.g., ear

plugs or muffs, if the noise level nearby precludes intelligible conversation by shouting or if a noise/sound level meter indicates above 90 dBA.

3. For excessive heat situations as well as noise problems, there are several published criteria for limiting the exposure. However, with heat it is usually more recognizable when one is approaching a critical exposure. Aluminized asbestos protective clothing can make the entering of burning structures tolerable for short periods. Vortex-cooled suits or the Cool Head™ Personal Cooling System (Acurex Aerotherm) permit work in hot and humid conditions.

Hazards

1. Carbon Monoxide (CO)

   Carbon monoxide is a tasteless, colorless, nonirritant gas, devoid of odor. It may be ignited by flames or objects above 610° C., if the CO concentration in air is between 12.5 percent and 74.2 percent. The molecular weight is 28 (or about the same density as air). One ppm by volume in air equals 1.145 mg/m^3.

   Carbon monoxide is a toxic chemical asphyxiant which combines with the hemoglobin of the blood 200-300 times as rapidly as oxygen, thereby preventing the absorption and distribution of oxygen to the tissues. Permanent damage to the brain and nervous tissue may result from lack of oxygen. Increased carbon dioxide concentration in air or decreased oxygen content (altitude) increases the susceptibility to carbon monoxide. Carbon monoxide has no warning properties. It is not cumulative

in the body from day to day since the reaction of CO and hemoglobin is reversible and time spent away from the abnormal concentration will permit complete elimination.

The TLV-TWA is 50 ppm; the TLV-STEL is 400 ppm. The emergency exposure levels are 400, 800, and 1500 ppm for 60-, 30-, and 10-minute exposures respectively. Thirty-five hundred (3500) ppm is immediately hazardous to life.

The CO level may be easily determined by the use of indicator tubes, infrared analyzers, or a catalytic oxidation indicator. Continuous recorders and alarms are also available. Laboratory analyses include the pyrotannic acid method, iodine pentoxide method, Haldane or Orsat gas absorption devices, and a calibrated gas chromatograph. Several methods for the determination of CO in the blood have been reported.

Since CO has no warning properties, only atmosphere-supplying respirators should be used when entering areas containing high levels of CO.

2. Carbon Dioxide (CO_2)

Carbon dioxide is a colorless, odorless, nonflammable gas which condenses to a solid at about -79° C. Its molecular weight is 44 and it is about one and one-half times as dense as air.

It is a normal constituent of the atmosphere ranging from about 300 to 600 ppm. Higher concentrations may naturally occur in mines, caves, tunnels, wells, and other places where oxidation, rot, decay, or other fermentation processes have depleted the oxygen with the formation of

carbon dioxide. In most combustion processes, carbon dioxide presents only a minor hazard in comparison with the other products of combustion, e.g., carbon monoxide. Fire extinguishers and building fire protection systems utilizing CO_2 and the use of the solid form (dry ice) for refrigeration may create excessive concentrations in confined areas.

One ppm is 1.8 mg/m^3. The TLV-TWA is 5,000 ppm; the TLV-STEL is 15,000 ppm; the respiration rate is markedly increased at 50,000 ppm. Concentrations of 80,000 to 100,000 ppm can be tolerated for as long as one hour without harm and level above 100,000 ppm are immediately hazardous to life. Most serious accidents involving carbon dioxide have resulted from asphyxiation rather than the direct effect of CO_2 itself.

Several direct field methods are available for determining the CO_2 concentration. These include indicator tubes, indicators containing a CO_2 absorbing fluid, infrared analyzers, thermal conductivity apparatus and interferometers. Grab samples may be analyzed in the laboratory by absorbing the CO_2 in a standardized solution and back-titrating with a standardized acid.

3. Oxides of Nitrogen

Nitrogen dioxide (NO_2) and its polymer nitrogen tetroxide (N_2O_4) are always found together at normal environmental temperatures. For example, at about 38° C. the ratio of NO_2 to N_2O_4 is 30:70. They are by-products of many operations and result whenever nitric acid acts upon metals or organic material. They are formed in

significant amounts from the slow burning or detonation of explosives, from electric arcs or electric and gas welding, in internal combustion engine exhaust, from the burning of nitrocellulose, from spillage of nitric acid, from the reduction of nitrates, etc.

NO_2 is a dark chocolate brown gas with a characteristically pungent and sweetish odor. It has a molecular weight of 46. N_2O_4 is a colorless gas. Below about -10° C., the gas is composed essentially of nitrogen dioxide. The mixture will hydrolyze readily in the presence of water to form a mixture of nitrous acid (HNO_2) and nitric acid (HNO_3).

Nitrogen dioxide exerts a local irritant and corrosive action in contact with moist body surfaces, including the skin and eyes. Most important is its severely irritating effect on the respiratory tract, particularly to the lower portions of the lungs.

Nitric oxide (NO) is a colorless gas which oxidizes readily in air to nitrogen dioxide. It is only about one-fourth as toxic as NO_2. It is not an irritant, however, it acts on the central nervous system to produce convulsions. It also combines with hemoglobin in the blood and interferes with oxygen uptake. Because it oxidizes so readily to NO_2, it does not constitute a significant hazard per se, the effects of NO_2 predominating. Precautions should therefore be geared to possible NO_2 exposures.

Nitrous oxide (N_2O) is also a colorless gas which has a very low order of toxicity. It behaves as a very weak anesthetic, but its main effect is that of an asphyxiant when present in air in sufficient quantities

to lower the oxygen content below levels which support life. It is used medically as an anesthetic (laughing gas).

Nitrogen pentoxide (N_2O_5) is a colorless solid, the anhydride of nitric acid. In moist air, it rapidly forms HNO_3. It is apparently stable in the presence of ozone and is readily formed when ozone is prepared from air. There is some evidence that when stabilized in the presence of ozone, it is more toxic than nitrogen dioxide and ozone.

One ppm of NO_2 in air equals 1.88 mg/m^3. The visual threshold is about 75-150 ppm, and the threshold of odor detection is about 5 ppm. The TLV-C for NO_2 is 5 ppm (2.5 ppm if calculated at N_2O_4). The emergency exposure levels are 10, 20 and 30 ppm for exposures to NO_2 for 60, 30 and 10 minutes respectively. Concentrations of 10-20 ppm are mildly irritating to the eyes, nose, and upper respiratory tract, but from 20-100 ppm there is very little difference in intensity of the reaction. Therefore, neither color, discomfort, nor visual threshold can be relied upon to provide adequate advance warning of dangerous levels in the atmosphere.

Detector tubes for measuring NO+NO_2 have been developed for field use. Field kits using the α-naphthylamine-nitrate reaction are available. The phenoldisulfonic acid method and the N-1-naphthylethylenediamine method have proven satisfactory for laboratory use.

Every precaution should be taken to insure that one does not enter areas where excessive concentrations of NO_2 may have accumulated. If entry is y, atmosphere-supplying devices should be used. All parts of

the body that may be exposed should also be covered through the use of suitable protective clothing.

4. Lead (Pb)

Lead is widely used in both the weapons and reactor fields because of its high density and good shielding properties. Lead and alloys of high lead content are widely employed where properties of softness, high density, low melting point, and resistance to corrosion are required. It is also a common minor component of many bronzes and free machining steels. Inorganic compounds are found in paint pigments, ceramics, plastics, insecticides, and storage batteries. Grinding and melting of lead and solder, and the spraying of lead paints, require good ventilation.

Lead dust and the dusts and fumes of all but the most insoluble compounds are readily absorbed on inhalation and, to a lesser degree, after ingestion. Lead and its inorganic compounds are not ordinarily absorbed through the skin. Conversely, organic lead compounds, such as tetraethyl lead (TEL) in gasoline, may be absorbed in fatal amounts by inhalation, ingestion, and through the skin. The amounts required for toxic effects are very minute and absorption is quite rapid.

Elemental lead is a dense silvery metal with a molecular weight of 207 and a density of 11.34. Its melting point is about 326° C., and lead fumes are evolved at red heat temperatures. For metallic lead and all inorganic lead compounds the TLV-TWA is 0.15 mg/m^3 and the TLV-STEL is 0.45 mg/m^3. Tetraethyl lead, TEL, is a flammable, colorless organic

liquid with a slightly sweet odor, and is used as an anti-knock compound in motor fuels. It has a TLV-TWA of 0.100 mg/m^3 and a TLV-STEL of 0.3 mg/m^3.

Lead-in-air sampling kits containing a pump, filter paper, and a set of reagents will yield an estimation in the field of the lead dust or fumes in the air. The fumes or dust may also be collected with an electrostatic precipitator, filter, or impinger, and subsequently analyzed by atomic absorption, polarographic, spectrographic, or dithizone procedures. The latter method is also recommended for TEL analysis when the contaminated air is collected in an alcoholic iodine solution.

Respirators with appropriate filters will successfully remove inorganic lead dust and fumes. Air purifying respirators with combination organic vapor/particulate canisters or atmosphere-supplying respirators may be used under certain conditions when handling organic lead compounds. In addition, the usual impermeable clothing, gloves, boots, etc., should be worn when the organic compounds are handled.

5. Beryllium (Be)

Beryllium is used in the atomic energy industry primarily for its nuclear properties.

It has been utilized as a cladding material for uranium, as a combined moderator and fuel element in conjunction with fissionable material, e.g., UBe alloy, and as a compact fuel element in reactors for rockets.

Because of its low density combined with high rigidity, beryllium metal is used in the aerospace and aircraft industries as a structural material.

Beryllium is a silvery white, brittle metallic element similar in appearance to magnesium, yet resembling trivalent aluminum so closely as to render its separation difficult. Its molecular weight is 9 and its density is 1.85. It will melt at 1285° C.

Acute disease may result from relatively brief inhalation exposure to high concentrations of beryllium or its compounds. The result may be a pneumonitis where exposure is to the metal, oxide, or other compounds. The pneumonitis may be very severe following massive exposure or less severe with gradual onset from lesser exposure. Chronic disease may develop from varying lengths of inhalation exposure to a wide range of concentrations. In some cases, there is a prompt onset of symptoms, while in others there may be a delay of months or years between the last exposure and the onset of symptoms.

Skin contact with soluble salts, particularly acidic salts, may produce primary irritation or a sensitization type of dermatitis.

The TLV-TWA for Be has been established as 0.002 mg/m^3. The TLV-STEL is 0.025 mg/m^3. A monthly average concentration of 0.00001 mg/m^3 has been used as a guide for the maximal atmospheric concentration outside manufacturing plants.

Air sampling is usually accomplished by means of filter paper or an electrostatic precipitator. These samples may be analyzed colorimetrically,

flourimetrically, or spectrographically. Various forms of beryllium monitors have been devised for recording the air concentration of beryllium continuously. Urine analyses and tissue analyses have also been developed.

Respiratory protective devices should be worn to minimize the inhalation hazard if enclosures and local exhaust ventilation are inadequately maintaining the Be in the air concentrations below the TLV. Air purifying respirators with high efficiency filters are acceptable for protection against beryllium. Half mask respirators should be restricted to atmospheric concentrations not exceeding 0.02 mg/m^3 (10 X TLV) and full face masks should be restricted to atmospheric concentrations where the contaminant does not exceed 0.2 mg/m^3 (100 X TLV). In emergencies where beryllium concentrations are unknown and hazardous conditions are possible, only National Institute for Occupational Safety and Health (NIOSH) approved self-contained breathing apparatus should be used.

Eye protective devices, gloves, and other protective clothing should not be worn away from the site. All clothing and other personal items contaminated with beryllium should be laundered separately, using facilities designed to prevent contamination of the air with Be.

6. Cadmium (Cd)

The largest use of cadmium is for electroplating. Cadmium metal and $Cd(NO_3)_2$ are used in reactors to control the rate of nuclear fission and as reactor poisons.

Cadmium is a silver-white, blue-tinged, lustrous, malleable, and very ductile metal. It volatizes and burns with a bright flame when heated in air, producing a brownish-yellow (Cd) fume. The molecular weight is 112.

Cadmium fumes have no pronounced odor or immediate irritating effect at concentrations sufficient to cause fatal injury.

Early sysmptoms of acute cadmium intoxication include dryness of the throat, coughing, constriction in the chest, shivering, etc. Later a pneumonitis develops with excruciating pain in the chest, severe labored breathing, and prostration.

The TLV-C of 0.05 mg/m^3 has been established for the cadmium oxide fume. From the study of a multiple-fatality accident, it was concluded that the lethal dose for man of thermally generated cadmium oxide fume is not over 2900 minutes - mg/m^3. This expression is the product of the concentration in mg/m^3 and the exposure time in minutes. The doses which caused incapacitation must have been considerably less. A case of cadmium pneumonitis occurred in a person exposed for three days to CdO during silver soldering in an inadequately ventilated enclosure. Concentrations of 0.5 - 2.5 mg/m^3 were measured in a reduplication of of the exposure conditions.

Microamounts of cadmium in the air may be determined by colorimetric dithizone methods, spectrographic methods, or a polarographic method.

Personal respiratory protective equipment, approved for protection against metal fumes, should be worn when the atmospheric concentrations of CdO exceed the TLV; half masks to 10 X TLV, full face masks to 100 X TLV, and atmosphere-supplying respirators above 100 X TLV.

7. Magnesium (Mg)

Magnox, magnesium containing 1 percent beryllium, has been used as a fuel-cladding material in low-temperature, gas-cooled power reactors. Magnesium is a light, silvery white metal with a molecular weight of 24. The pure metal melts at 649° C. The ignition temperature for finely divided magnesium alloys may be below 482° C.

The health hazards are low for both acute and chronic exposures. However, metal fume fever has been experienced by men who have inhaled excessive concentrations of the oxide fume from heated magnesium. Magnesium dust is somewhat irritating to mucous membranes.

The TLV-TWA and TLV-STEL for magnesium oxide fume is 10 mg/m^3.

Magnesium oxide fume can be determined colorimetrically, using Titan Yellow in samples collected by an electrostatic precipitator, or by spectrographic methods.

8. Alkali Metals

Experimental nuclear reactors containing large quantities of the alkali metals as coolants have been constructed and operated.

Sodium (Na) is a light, ductile, silvery metal with a molecular weight of 23. It reacts violently with water and most common solvents. The

metal or its vapor may ignite spontaneously in air at temperatures above 115° C., the resulting smoke, chiefly sodium oxide, is a serious respiratory hazard. Sodium fume or smoke resulting from the escape of hot sodium vapor to the atmosphere, with or without combustion, may contain micrometer and even submicrometer particles of sodium, sodium oxide, and sodium hydroxide, all of which may penetrate the respiratory tract. The result is a corrosive action and extreme irritation largely in the nose, throat, and upper respiratory passages. The irritant action serves as an effective warning.

An alloy of sodium and potassium in any proportions, known as NaK, has also been employed as a heat-transfer fluid in reactors. Metallic potassium is similar to, but more reactive than, sodium. Therefore, NaK must be used, handled, and stored with great care. Respiratory protection is also required when there is a possibility of potassium or NaK contamination.

Permissible levels of exposure have not been determined. Adequate respiratory protection is advisable whenever one must enter an area possibly contaminated with sodium.

Lithium (Li) and hydrides of lithium, both simple (LiH) and complex ($LiAlH_4$), are used in atomic energy and in the chemical industries.

Lithium is the lightest metal. Although it belongs to the alkali metals, it sometimes resembles the alkaline earths.

Lithium is the lightest metal. Although it belongs to the alkali metals, it sometimes resembles the alkaline earths.

Lithium can be relatively toxic to man and animals, and its toxicity is determined not only on the amount of Li involved, but also on the amount of sodium intake. The primary toxic effect of Li on animals has been on kidney function. The toxicity of LiH by inhalation for animals is marked by irritancy and corrosiveness.

The chief hazards in the handling of lithium hydrides are dust protection, static electricity, and fire. A fire once started cannot be extinguished by ordinary means; smothering by dolomite power is recommended.

The only Li compound for which a limiting concentration in air has been set is LiH. The TLV-TWA and TLV-STEL is 0.025 mg/m^3 based on an acute response (irritation).

9. Zirconium (Zr)

Zirconium sponge is used mainly for military purposes and in private power reactors. Zirconium alloys resist neutron bombardment and corrosion, and have a low neutron-capture cross section. It is also used in flash bulbs, as a deoxider for iron and steel, and in ceramics. Sponge Zr is pyrophoric when pure, and violently explosive when impure. Zirconium is a white-gray solid, commercially available in massive forms, such as ingots, bars, rods, or foil, and as powder. The molecular weight is 91. It melts at 1899° C. There are no identifying characteristics of taste, odor, or irritation. The

TLV-TWA for zirconium compounds is 5 mg/m^3. The TLV-STEL is 10 mg/m^3. There is also an extreme fire and explosion hazard when in the form of machine turnings, chips, powder, or dust.

The health hazards associated with zirconium are low for both acute and chronic exposures. There has been no occupational case of systemic poisoning reported. Administration of Zr and its compounds to animals orally, and by inhalation, produces no significant chronic or acute effects.

There are no direct Zr measuring instruments available. Determination by spectrographic procedures is recommended. There is also an electrophoresis and a color development (chloranilic acid) method.

Acids

Many times radioisotopes are employed in acidic solutions. Radioactive wastes may be shipped in acidic solutions, etc., therefore, the properties of several common acids will be discussed.

Sulfuric acid (H_2SO_4) is a strongly corrosive, hydroscopic, dense, oily liquid, colorless to dark brown depending on purity. Its molecular weight is 98 and boiling point is 210° to 338° C.

Sulfuric acid is intensively irritating and corrosive to the skin, eyes, respiratory passages and gastrointestinal tract.

One ppm equals 4.01 mg/m^3. The TLV-TWA and TLV-STEL is 1 mg/m^3. Its sharp penetrating odor is noticeable at 1 mg/m^3 by most people. Concentrations greater than 3 mg/m^3 would probably not be tolerated for long.

Sulfuric acid mist may be collected on millipore filters and the filter washings determined by electrical conductivity. It may also be collected with impingers and titrated with a standard base.

Nitric acid (HNO_3) is a colorless to light brown liquid with an acrid odor. Strengths above 85.7 percent are considered fuming nitric acids. Red fuming nitric acid contains, in addition, varying percentages of nitrogen oxides in solution. Every precaution should be taken to prevent exposures to nitric acid in liquid or vapor form.

The TLV-TWA for nitric acid is 2 ppm or 5 mg/m^3. The TLV-STEL is 4 ppm or 10 mg/m^3. The TLV-C for nitrogen dioxide is 5 ppm or 9 mg/m^3.

Conductivity analyzers may be used in the field, but they are not specific. The vapor may be collected by bubbling through a fritted glass disc and using dilute alkali as the absorption medium, and the nitrate content estimated by one of the colorimetric methods.

Hydrochloric acid (HCl) is an aqueous solution of hydrogen chloride, a clear, colorless gas with a sharp smell and acid taste. Concentrated hydrochloric acid solution contains about 38 percent HCl. One ppm equals 1.49 mg/m^3.

HCl is a powerful primary irritant of the skin, eyes, and mucous membranes. Inhalation results in the destruction of tissues of the respiratory tract, and it will cause inflammation of the eyelids with some damage to the eye itself. The TLV-C for HCl is 5 ppm or 7.0 mg/m^3. The emergency exposure limits are 10, 20, and 30 ppm for periods of 60, 30, and 10 minutes,

respectively. Concentrations of 1000-2000 ppm are immediately dangerous to life.

HCl may be collected in water and the electrical conductivity is then measured. The acid or chloride content of samples collected in water or alkaline solutions may be determined by acidimetry or titration, respectively. Nephelometry using silver nitrate may also be employed.

Hydrofluoric acid (HF) is an aqueous solutuion containing hydrogen fluoride. It is a colorless, extremely corrosive gas with a sharp penetrating odor. One ppm of monomolecular HF vapor equals .0818 mg/m^3.

Hydrofluoric acid is an extremely hazardous chemical because of its violently irritating and corrosive effect on the skin, eyes, mucous membranes, and respiratory tract.

It is easily and rapidly absorbed through the skin where it exerts a very extensive destructive action on underlying tissues.

The TLV-TWA and TLV-STEL is 3 ppm or 2 mg/m^3. The following emergency exposure limits have been established: 8 ppm for 60 minutes, 10 ppm for 30 minutes, and 20 ppm for 10 minutes.

HF may be determined by spectrophotometric, fluorometric, or polarographic methods. It may be collected in 1 percent sodium hydroxide in an evacuated bulb, with subsequent back titration of free alkali.

Acetic acid (CH_3COOH) is frequently given the symbol HAc. Glacial acetic acid (99.5 percent pure) is a clear, colorless liquid with a pungent odor;

when diluted, the odor and taste resemble vinegar. One ppm equals 2.55 mg/m^3. Acetic acid is irritating and corrosive to the skin, eyes, respiratory passages, and gastrointestinal tract.

The TLV-TWA is 10 ppm or 25 mg/m^3. The TLV-STEL is 15 ppm or 37 mg/m^3. 200-500 ppm is extremely irritating but may be tolerated for brief periods by some individuals.

It may be collected in an all-glass device containing a 1:1 mixture of glycerol and water and Fleisher methyl purple. Calibration of the reagent gives a measure of total acid in the air.

Phosphoric acid (H_3PO_4) is 50, 75 or 85 percent aqueous solution of the colorless, odorless crystals of orthophosphoric acid. It is a moderately corrosive mineral acid, causing skin, eye, and respiratory tract irritation. Solutions of 75 percent or greater cause destruction of body tissues and severe burns. The TLV-TWA of phosphoric acid is 1 mg/m^3. The TLV-STEL is 3 mg/m^3.

Atmospheric concentrations may be determined by collection in a sodium hydroxide solution in an impinger or sintered glass bubbler, followed by titration of free acid.

Atmosphere-supplying respirators should be used if it is necessary to enter an area where excessive acid concentrations may exist; canister-type gas masks do not provide adequate protection. Acid-resistant protective clothing and gloves should be worn covering all portions of the body that may be

exposed. Eye contact should be prevented through the use of acid-proof goggles, face shield, or a complete acid-proof hood.

Bases

Radioactive wastes are sometimes transported in basic solutions. Therefore, the hazards of several of the more common bases or alkalis will be reviewed.

Sodium hydroxide (NaOH) is also known as caustic soda or lye. It is available as a solid containing 98 percent NaOH or as a liquid containing 45 to 75 percent sodium hydroxide. The molecular weight of the white lumps, sticks, or pellets is 40.

In solid form or concentrated solution, sodium hydroxide is intensely irritating and corrosive to the skin, eyes, respiratory passages, and gastrointestinal tract. Even dilute solutions exert a destructive effect on tissues, especially the eyes. The TLV-C is 2 mg/m^3.

Potassium hydroxide (KOH), also known as caustic potash, exists as white delinquesient pellets, sticks, or cake. The molecular weight is 56. It produces physiological responses similar to that for sodium hydroxide. The TLV-C is 2 mg/m^3.

Ammonium hydroxide (NH_4OH) is a 10 percent or 28 percent solution of ammonia in water. These solutions vaporize and the crystalline solids, ammonium carbonate and ammonium carbamate, decompose in the air to release ammonia, a colorless gas with a characteristic strong and pungent odor said to be detectable at concentrations less than 5 ppm in air. The TLV-TWA for ammonia is 25 ppm or 18 mg/m^3. The TLV-STEL is 35 ppm or 27 mg/m^3.

Ammonia (NH_3) is extremely irritating and highly corrosive to the eyes and respiratory tissue. Suffocation and death from pulmonary edema can result from exposures to high concentrations. Its irritating properties and pungent odor give adequate warning of its presence in the atmosphere before hazardous concentrations can accumulate. Discomfort is generally experienced at concentrations above 25 ppm. Concentrations greater than 400 ppm cause increasingly severe irritation of the mucous membranes of the eyes and respiratory passages, and may destroy mucous surfaces. The lips, tongue, and eyelids swell. Above 1700 ppm, breathing alledgedly becomes difficult and a choking, spasmodic cough persists. It is estimated that exposures of 2500 to 4500 ppm would be dangerous to life within one-half hour. Concentrations above this are rapidly fatal. If a toxic exposure is not fatal, bronchopneumonia may develop. The eyes are particularly sensitive to gaseous ammonia and to aqueous ammonia solutions (NH_4OH). Direct contact may lead to permanent scarring and, in some instances, to partial or total loss of vision.

Calcium hydroxide ($Ca(OH)_2$) is only very slightly soluble in water; therefore, its aqueous solutions are not corrosive. High concentrations of the dust in the air would be irritating.

Sodium peroxide (Na_2O_2) is made by oxidizing sodium with dry air, first to the monoxide, then to the dioxide. Physiological responses are similar to those from exposures to sodium hydroxide except for a greater hazard of airborne dust. It has been suggested that the TLV should not be greater than 2 mg/m^3

Potassium and sodium carbonate dusts or concentrated aqueous solutions are irritating and corrosive. They are strongly alkaline, but exert a less potent caustic action than their respective hydroxides. Although no TLV's have been established, they could be somewhat higher than that permissible for the hydroxides.

Caustics and other alkaline materials in the atmosphere, whether gases, mists, or dusts, may be determined by scrubbing a measured volume of air through a measured amount of standard sulfuric acid and titrating the excess acid with standard alkali. The analysis may be completed in the field using a suitable quantity of standard sulfuric acid scrubbing agent containing methyl red or other appropriate indicator, and noting the time required for scrubbing a measured rate of air until the indicator changes color.

Skin and eye contact with the solid and solutions should be prevented by the use of suitable protective clothing, including close-fitting eye goggles at all times. Respiratory protection should be provided whenever it is necessary to work in areas where the TLV cannot be maintained.

Fuels, Propellants and Oxidizers

Nuclear devices constructed for national defense or research purposes may be transported by jet aircraft or some type of missile or rocket. It is therefore possible that radiological emergencies may occur which will involve personnel exposures to chemicals which power these vehicles.

Jet fuels, turbo prop fuels, and kerosene are similar chemically, consisting of aliphatic, olefinic, naphthenic (cycloparaffinic) and aromatic hydrocarbons. The principle components are aliphatics ranging from C_5 to C_{16}. Because of their relatively low vapor pressure, inhalation toxicity is unlikely under ordinary conditions of use. The inhalation of mists should be avoided, however, because of the possibility that a chemical pneumonia might result. Exposure to mists will also cause mucous membrane irritation. Prolonged or repeated contact with skin will result in drying and dermatitis. The threshold limit for these hydrocarbon mixtures has not been established. Dozens of chemicals and chemical combinations have been studied for use as rocket propellants and oxidizers. Because of their chemical reactivity, which makes their use as propellants promising, these chemicals also have properties which are detrimental to biological systems.

Hydrazine (N_2H_4) is a potent irritant which can cause local damage to the skin or the eyes where it will produce a typical chemical burn. It may produce permanent corneal opacity. If it is inhaled in sufficient quantities, it is a respiratory tract irritant, and if sufficient quantities are absorbed into the blood stream, it will affect the central nervous system resulting in tremors and convulsions. The odor threshold is 3-4 ppm. The TLV-TWA for hydrazine has been set at 1 ppm. It can be absorbed through the skin. The emergency exposure limits for hydrazine are 10, 20, and 30 ppm for exposures of 60, 30, and 10 minutes, respectively. It may be determined in the atmosphere by a method using electrical conductivity measurements. The vapors may be collected in sulfuric acid, phosphomolybic acid, and subsequent determination by titration, colorimetry or potentiometry.

1, 1-Dimethylhydrazine [$(CH_3)_2NNH_2$], (UDMH), is mildly irritating to the skin and eyes and appears to be a more potent stimulant than hydrazine, insofar as the central nervous system is concerned. Tremors and convulsions have been noted. It is absorbable through the skin. The TLV-TWA is 0.5 ppm or 1 mg/m^3. The TLV-STEL is 1 ppm or 2 mg/m^3. Two sets of emergency exposure limits for UDMH have been published. They are as follows: 30, 50 and 100 ppm for 60-, 30- and 10-minute exposures and 10, 20, 35 and 50 ppm for 60-, 30-, 20-, 15- and 5-minute exposures. Atmospheric concentrations may be determined by several commercially available detectors or collection of the vapors in aqueous solutions and titration with potassium iodate or colorimetric determination by a molybdenum blue method.

Pentaborane, B_5H_9, is very toxic when inhaled in low concentrations. It is also extra hazardous by ingestion or skin absorption. It may cause kidney and liver damage. The odor threshold is 1 ppm, however, the TLV-TWA is only 0.005 ppm or 0.01 mg/m^3. The TLV-STEL is 0.15 ppm or 0.03 mg/m^3. There is no analytical detection method specific for pentaborane. Collection on specially activated carbon, with subsequent hydrolysis and determination as boric acid, is possible.

Hydrogen peroxide (H_2O_2) is used as an oxidizer for high-energy fuels and as an organic oxidant bleaching agent. The inhalation hazard is moderate. Skin and eye contact with the liquid will produce tissue destruction. The eyes do not appear to be damaged from exposure to the vapor. The TLV-TWA is 1 ppm or 1.4 mg/m^3. The TLV-STEL is 2 ppm or 2.8 mg/m^3. The short exposure tolerance for man has been estimated as 75 ppm. The titanium sulfate method is satisfactory for determining air concentrations.

Nitrogen tetroxide (N_2O_4) is an oxidizer. As discussed earlier, it exists in equilibrium with nitrogen dioxide. The TLV-C is 5 ppm or 9 mg/m^3 and the EEL's are 10, 20 and 30 ppm for 60-, 30- and 10-minute exposures, respectively.

Chlorine trifluoride (ClF_3) and perchloryl fluoride (ClO_3F) are both powerful oxidizing agents. Chlorine trifluoride is extremely corrosive and will cause deep burns on contact with the skin or eyes. It is also a severe irritant of the upper and lower respiratory tracts and is capable of producing pulmonary edema if the concentration is sufficiently high. It has a TLV-C of 0.1 ppm or 0.4 mg/m^3.

Liquid perchloryl fluoride may produce moderately severe burns if allowed to remain in contact with the skin for a sufficient period of time. Inhalation exposure to moderate or high concentrations of the vapor can produce a respiratory irritation and pulmonary edema. The TLV-TWA is 3 ppm or 14 mg/m^3. The TLV-STEL is 6 ppm or 28 mg/m^3.

N-Propyl nitrate ($C_3H_7NO_2$) is also a skin irritant. Repeated contact produces a yellow discoloration of the skin. Inhalations of high concentrations of the vapor are irritant to the respiratory tract and may produce methemoglobinemia. Because of its low volatility, the likelihood of toxic effects from exposure is not as great as in the case of other volatile propellants. The TLV-TWA is 25 ppm or 110 mg/m^3. The TLV-STEL is 40 ppm or 140 mg/m^3.

A typical double-base solid missile propellant is made up of nitrocellulose and nitroglycerine. The latter is not only absorbed through the lungs if contaminated air is breathed, but also is readily absorbed through the

intact skin. It will pass through certain types of so-called impermeable materials commonly used in protective gloves and clothing. Nitroglycerine is a systemic poison causing a lowering of the blood pressure, central nervous system symptoms and skin eruptions. The TLV-TWA and TLV-STEL is 0.2 ppm or 2 mg/m^3.

Composite (solid) propellants are made up of a variety of chemicals. They are chiefly resinous fuel binders, either plastics or synthetic rubbers, to which are added inorganic crystalline oxidizers, e.g., ammonium perchlorate and small amounts of chemical additives. These materials are absorbed through the lungs, skin, and digestive tract. The TLV-TWA and TLV-STEL for diborane is 0.1 ppm or 0.1 mg/m^3.

The major constituents of the combustion products of a propellant system can be predicted if the chemical composition of the propellant is known. From the combustion of a hydrocarbon propellant, one would expect to find carbon monoxide. If the propellant contains nitrogen, the oxides of nitrogen will be produced. A sulfur-containing propellant, when combusted, will produce toxic and irritant gases, including sulfur dioxide, sulfur trioxide, and hydrogen sulfide. If the propellant contains chlorine, the combustion products will contain hydrochloric acid and chlorine. If it contains flourine, one expects hydrofluoric acid and fluorine. In the case of propellants containing metallic atoms, the combustion products will usually contain the free metal and the metal-oxide, -halide, -hydroxide, and -nitride.

TABLE 1
EXPOSURE LIMITS

SUBSTANCE	THRESHOLD LIMIT VALUE TWA PPM	TWA Mg/M^3	STEL PPM	STEL Mg/M^3	EEL FOR TIME UP TO 10 MINUTES	30 MINUTES	60 MINUTES
BERYLLIUM (Be)	---	0.002	---	0.025	---	---	---
CADMIUM (Cd)	---	0.05	---	0.015	---	---	---
CARBON DIOXIDE (CO_2)	5000	9000	15000	18000	---	---	---
CARBON MONOXIDE (CO)	50	55	400	440	1500 ppm	800 ppm	400 ppm
CHLORINE TRIFLUORIDE (ClF_3) - "C"	0.1	0.4	---	---	7 ppm	3 ppm	1 ppm
DIBORANE ($B2H_6$)	0.1	0.1	---	---	10 ppm	5 ppm	2 ppm
1,1-DIMETHYLHYDRAZINE (UDMH) - "SKIN"	0.5	1	1	2	100 ppm	50 ppm	30 ppm
HYDRAZINE (N_2H_4) - "SKIN"	0.1	0.1	---	---	30 ppm	20 ppm	10 ppm
HYDROGEN PEROXIDE (H_2O_2)	1	1.4	2	2.8	---	---	---
LEAD (Pb)	---	0.15	---	0.45	---	---	---
MAGNESIUM (Mg)	---	10	---	---	---	---	---
NITROGEN DIOXIDE (NO_2) - "C"	5	9	---	---	30 ppm	20 ppm	10 ppm
NITROGENTETROXIDE (N_2O_4)	See NO_2		---	---	---	---	---
NITROGLYCERINE - "SKIN"	0.2	2	---	---	---	---	---
PENTABORANE (B_5H_9)	0.005	0.01	0.015	0.03	---	---	---
PERCHLORYL FLUORIDE (ClO_3F)	3	14	6	28	50 ppm	20 ppm	10 ppm

TABLE 1 (CONTINUED)
EXPOSURE LIMITS

SUBSTANCE	THRESHOLD LIMIT VALUE				EEL FOR TIME UP TO		
	TWA		STEL				
	PPM	Mg/M^3	PPM	Mg/M^3	10 MINUTES	30 MINUTES	60 MINUTES
n-PROPYL NITRATE ($C_3H_7NO_2$)	25	110	40	140	---	---	---
TETRAETHYL LEAD (TEL) - "SKIN"	---	0.100	---	0.3	---	---	---
ZIRCONIUM (Zr)	---	5	---	10	---	---	---
ALKALI METALS							
Lithium (Li)	---	0.025	---	---	---	---	---
Sodium (Na)	---	---	---	---	---	---	---
ACIDS							
Acetic Acid (CH_3COOH)	10	25	15	37	---	---	---
Hydrochloric Acid (HCL) - "C"	5	7	---	---	30 ppm	20 ppm	10 ppm
Hydrofluoric Acid (HF)	3	2	---	---	30 ppm	10 ppm	8 ppm
Nitric Acid (HNO_3)	2	5	4	10	---	---	---
Phosphoric Acid (H_3PO_4)	---	1	---	3	---	---	---
Sulfuric Acid (H_2SO_4)	---	1	---	---	5 mg/m^3	2 mg/m^3	1 mg/m^3
BASES							
Ammonia (NH_3)	25	18	35	27	500 ppm	300 ppm	300 ppm
Potassium Hydroxide (KOH) - "C"	---	2	---	---	---	---	---
Ammonium Hydroxide (NH_4OH)	---	---	---	---	---	---	---
Sodium Hydroxide (NaOH) - "C"	---	2	---	---	---	---	---

SECTION 22

PROTECTIVE EQUIPMENT

One of the primary personnel hazards on entering a contaminated environment is the ingestion of radioactive material into the body. An attendant problem is preventing the spread of contamination to uncontrolled areas by personnel exiting a contaminated area.

ANTI-C CLOTHING

Anti-contamination clothing, respiratory devices and the establishment of proper area controls will effectively reduce the problems of personnel contamination. Anti-contamination clothing is worn to prevent radioactive particles from reaching the body and as an aid in preventing the spread of contamination to radiologically clean areas.

Civilian work clothing or military fatigues can provide some protection from contamination and, in an emergency, could be worn in lieu of special anti-contamination clothing. Occasionally, for the sake of public relations or to expedite rescue operations, it may be desirable to wear ordinary work clothing into a contaminated area. Any clothing worn in such an environment must be considered expendable and should be processed in the same manner as anti-contamination clothing.

Some important factors which influence the selection of anti-contamination clothing are: the weather conditions expected at the scene, the nature and quantity of the contaminant, and the environment in which the clothing is to be worn. Since these factors are variable, equipment which can be adapted to a variety of situations may be more useful than single purpose items. Several items of anti-contamination clothing and their uses are briefly described below:

In highly contaminated areas, underclothing (socks, shorts and undershirts) should be worn which can be disposed of or laundered at decontamination facilities.

Heavy-duty, close weave, cotton twill, single piece coveralls which cover all but the feet, hands and head have been worn satisfactorily in dry, highly contaminated areas. Such coveralls are effective in preventing most of the contamination from penetrating to underclothing and skin (Figure 1). A second pair of coveralls is usually worn over the first pair to allow removal of highly contaminated clothing before proceeding to a primary decontamination facility. Button seams, pocket slits, and small tears or holes in coveralls should be covered with masking tape. A one-inch fold-over tab should be made on the exposed end of the tape at each sealed juncture for ease in removing from the anti-contamination clothing (Figure 2).

Shoes which are expendable should be worn in highly contaminated areas, as protective coverings and decontamination methods are sometimes ineffective. Shoe covers are available in several materials and sizes. Low snap-on canvas or plastic covers are frequently worn in areas of low-level contamination (Figure 3). Rubber boots or galoshes are usually worn in wet areas. Hightop rubber shoe covers which are rugged and waterproof are practical for most work in contaminated areas (Figure 4).

A surgeon's cap is worn to minimize contamination of the hair and scalp. Plastic or cloth hoods are worn in grossly contaminated areas or locations where there may be a great deal of airborne contamination (Figure 5).

Work gloves of cotton, canvas, or plastic are often used in contaminated areas to perform jobs which entail manual labor. Surgeon's gloves are used for jobs which require sensitivity of touch and they are usually worn under work gloves in highly contaminated areas to give added protection. Rubber gauntlet gloves are used where corrosive liquids, caustics, or wet contaminants are handled. Outer gloves worn in contaminated areas should overlap the wrist of the coveralls and should be taped at the juncture of the glove and wrist. Inner gloves should have the sleeves of the coveralls overlap them.

Plastic suits can be divided into two general categories. One type requires an external source of supplied air (Figure 6), and a second type can be worn with respiratory devices or a self-contained breathing apparatus (Figure 7). The first type of plastic suit is widely used in permanent installations as it affords excellent protection in almost any contaminated atmosphere. However, it is cumbersome, tears easily, requires considerable supplementary equipment to function properly, and is not easily adapted to field operations.

The second type of plastic suit also affords good protection in highly contaminated areas. Its chief advantage is impermeability to water and many gaseous toxic agents. It tears easily, is uncomfortable to wear, and is somewhat bulky.

In wet, contaminated environments, standard rain gear may be worn over anti-contamination clothing if necessary. The prime requisite is impermeability of the clothing used. Coats, sweatshirts, and all other items of apparel that could be mistaken for street wear should be conspicuously marked and their use restricted to contaminated areas.

Laboratory coats or company-owned cotton trousers and shirts are the most universally utilized types of anti-contamination apparel and are used in areas of low contamination potential. These type garments are usually worn over personal clothing. They are lightweight and easily removed but afford only minimal protection.

The Hot Line

Monitoring personnel should have a standard procedure and a designated area for removing contaminated clothing after returning from contaminated areas. The designated area is usually referred to as a hot line (Figure 8).

One or two monitors should be available at the hot line to perform personnel monitoring and to assist with the removal of anti-contamination clothing.

Normally, monitors returning from contaminated areas should perform the following:

1. Place instruments and equipment on an area covered with paper or polyethylene, located on the hot side of the hot line.

2. Remove tape and place in marked container such as a polyethylene bag.

3. Be monitored by a hot line monitor who will pay special attention to hot spots on back of neck, hands, and feet.

5. Remove coveralls and place in container.

6. Remove one shoe cover, place in container, and step over hot line to cold side.

7. Remove remaining shoe cover and step over hot line.

8. Remove (or allow hot line monitor to remove) respirator and surgeon's cap and place on container.

9. Slip off gloves, without touching outside surface, and place in container.

10. Be monitored by hot line monitor.

11. Wash up.

12. Be monitored again, if any skin contamination was previously detected.

If two pair of coveralls, gloves, and shoe covers are worn in contaminated areas, the recommended sequence for removal of anti-contamination clothing would be:

1. Tape
2. Hood
3. Outer gloves
4. Outer coveralls
5. Outer shoe covers
6. Inner coveralls
7. Inner shoe covers
8. Respirator and surgeon's cap
9. Inner gloves

Respiratory Protection

Respiratory protection is based upon the very simple idea of protection of the worker by air purification or supplying safe, clean breathing air to the worker. The manner and methods to accomplish this are varied and at times involved.

The best method is to engineer the hazard out of existence or to a non-harmful level. When that is not possible, the use of respiratory protection is the next best solution.

There are many variables involved in the use of respiratory protection at any given time or location:

1. Degree and type of the hazard.
2. Selection of people to perform the work.
3. Selection of appropriate equipment for the job.
4. Physical abnormalities of the work site or the work.

There is no single solution to respiratory protection problems. Therefore there are many views, guidelines, manuals, publications, and information available. The following "Basic Elements of Respiratory Protection", provided through the courtesy of Mine Safety Applicances Company, presents basic information for guidance purposes. Its inclusion does not constitute an endorsment of the products discussed therein. More complete information can be found in the references listed in the booklet and in the U. S. Nuclear Regulatory Commission NUREG-0041 "Manual of Respiratory Protection Against Airborne Radioactive Materials" available from National Technical Information Service, Springfield, Virginia 22161.

Figure 1 Coveralls and Cloth Cap

Figure 2 Taped Coveralls with Mask

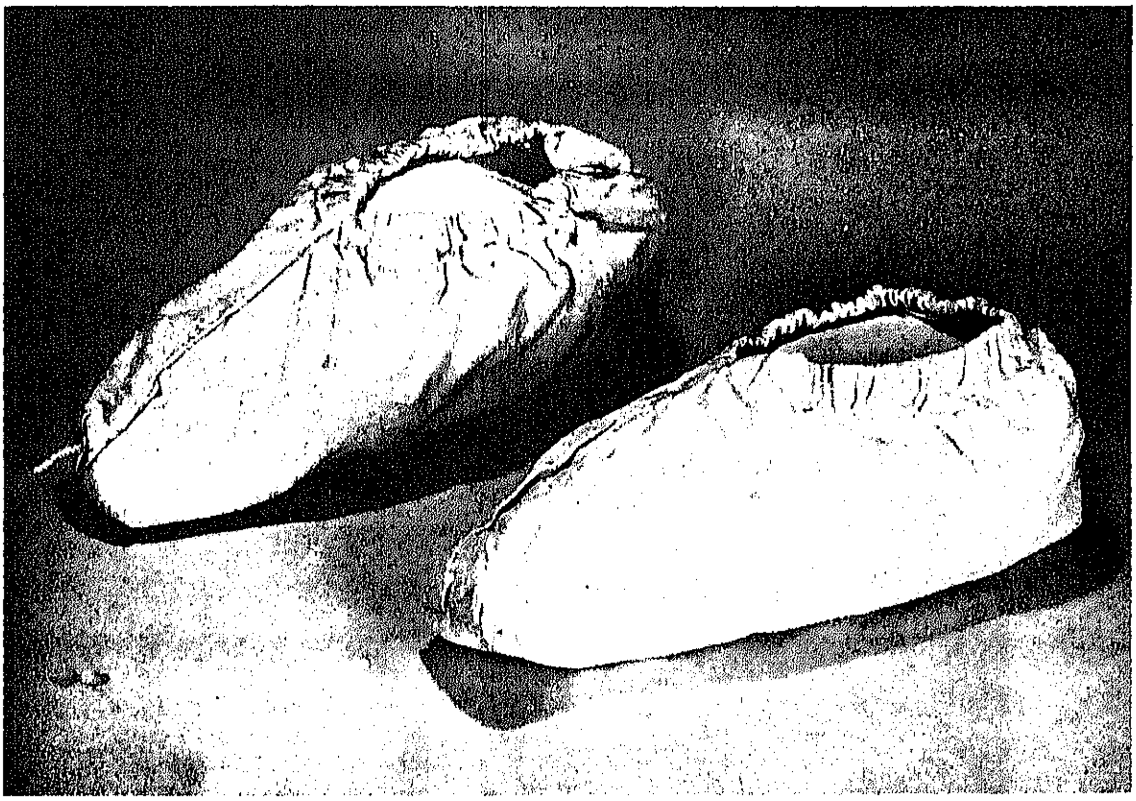

Figure 3 Canvas Shoe Covers

Figure 4 Rubber Shoe Cover (Taped)

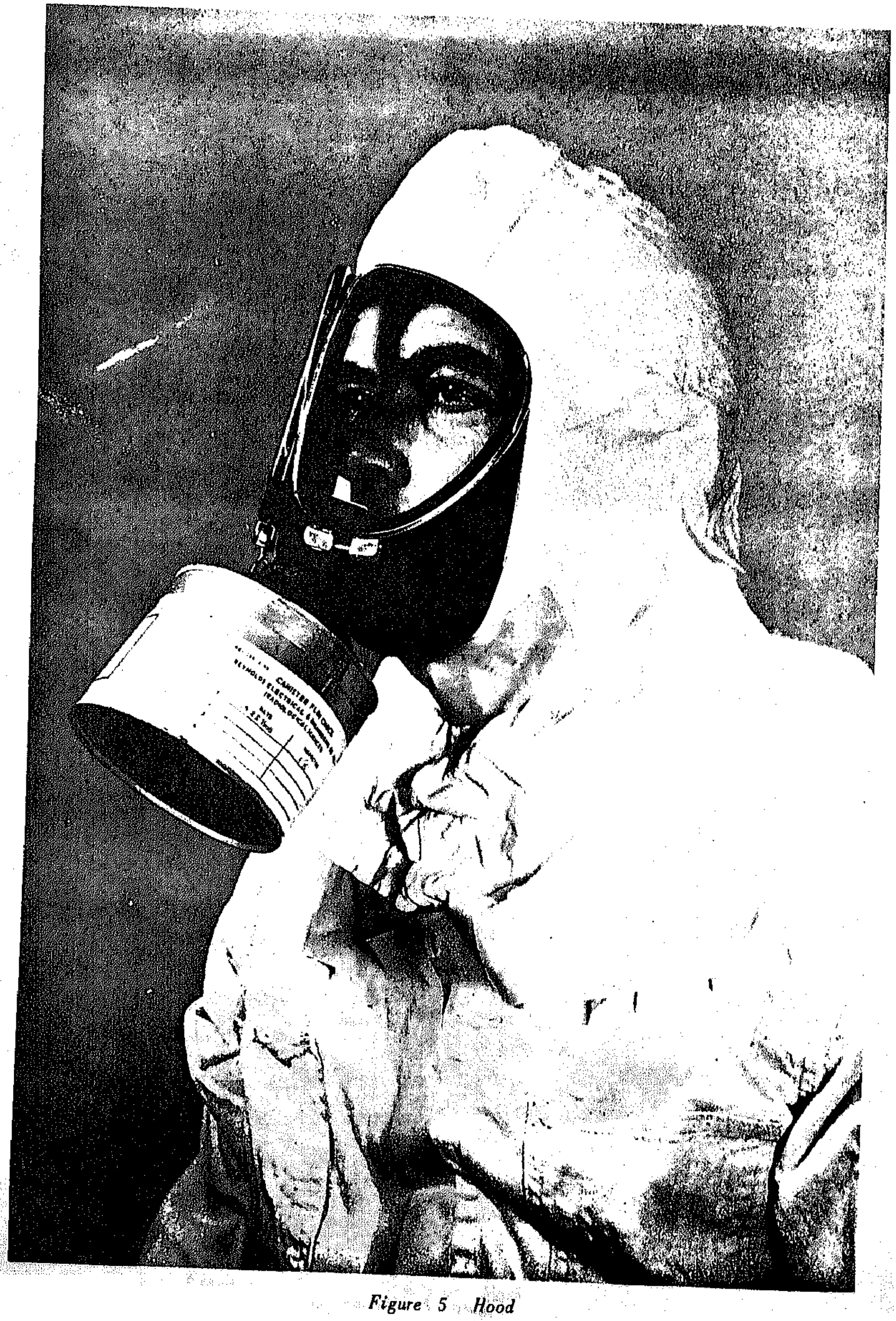

Figure 5 Hood

Figure 6   Air-Supplied Plastic Suit

Figure 7 Self-Contained Plastic Suit

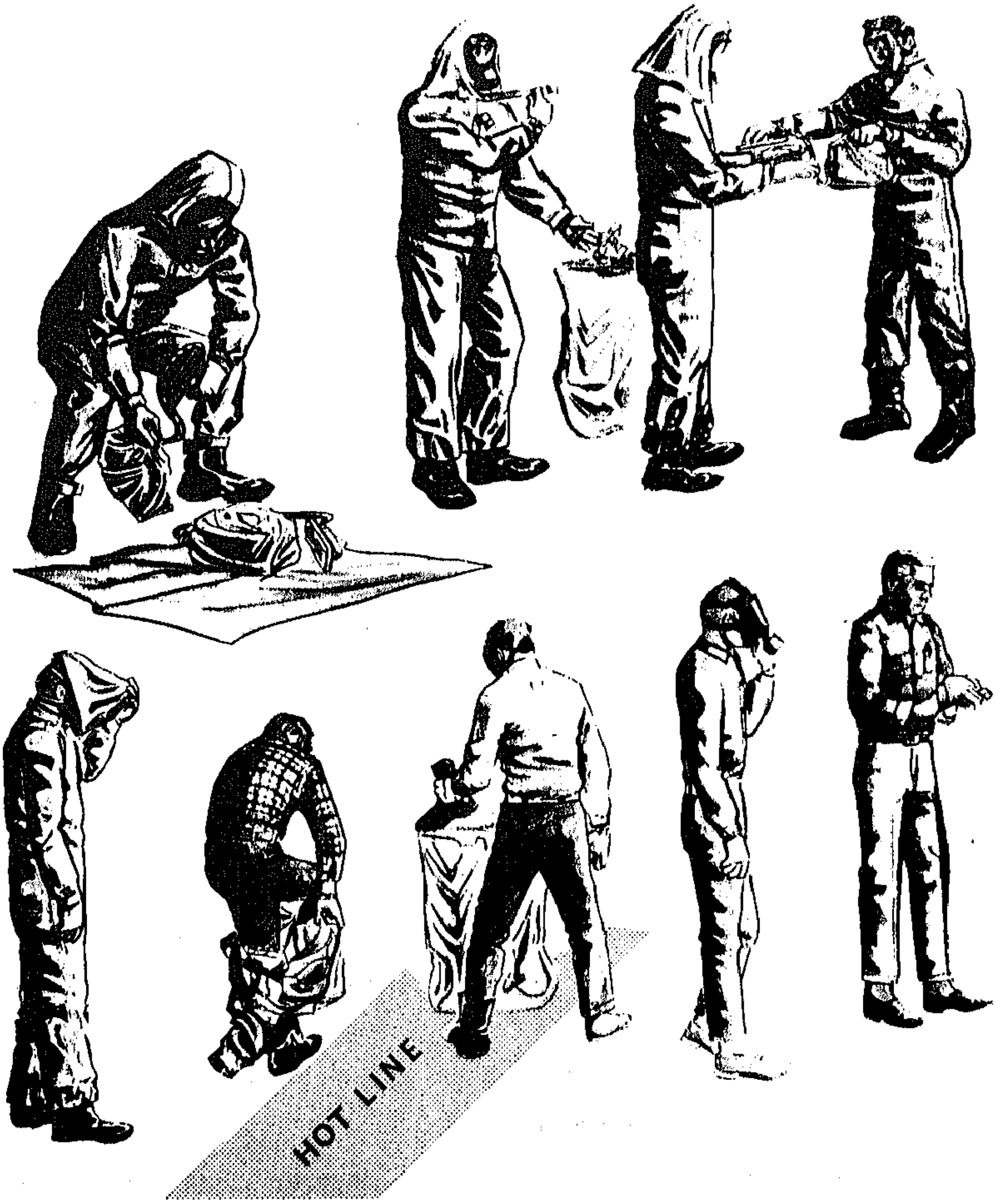

Figure 8 Hot Line

SECTION 23

DECONTAMINATION

The purpose of decontamination is to remove and control radioactive material and thus prevent it from being inhaled, ingested, or absorbed through the skin. Decontamination is also performed to remove and control radioactive materials that present external radiation hazards.

The organization responsible for the radioactive material will be responsible for decontamination efforts. They will also be responsible for necessary health protection precautions taken by those persons performing the decontamination. However, the support organization may be called upon for advice in appropriate decontamination methods, proper health control measures for the performance of the necessary work, and decontamination assistance for the immediate protection of personnel.

Monitoring personnel may be faced with problems requiring rapid and proper decisions concerning decontamination. These decisions, if made early enough, will have a great bearing on the total success of the operation. One of the prime objectives is the protection of the public. Every decision should be weighed in the light of good radiological safety procedures.

One consideration which is easily overlooked is that of the possibility of psychological reactions when the public encounters the use of anti-contamination clothing and respiratory devices at the scene of an accident. Such equipment should be used only after a careful appraisal and responsible decision has been made regarding actual need of the equipment. Naturally, in attempting to make a decision regarding the use of protective clothing and equipment, the amount and nature of the contamination must first be known.

General Methods of Decontamination

All personnel should be monitored before leaving the contaminated area. If facilities are available, all personnel should take showers using soap and water even when monitoring indicates no skin contamination.

To prevent the spread of contamination to clean areas, all equipment and material should be decontaminated to permissible levels before being released from the contaminated area.

Scrap metal, wood, equipment damaged beyond repair, and other debris should be considered as waste material and should be disposed of in a suitable manner. Waste which is contaminated requires special and careful handling to prevent accidental personnel exposure and possible spread of the contamination.

Clothing, tools, equipment, and other usable materials which are contaminated should be considered waste when time and effort spent in decontamination efforts would exceed the value of these materials. The probable success or failure of decontamination methods and the nature of the situation are other factors that must be considered in declaring usable materials as waste.

Radioactive emitters which are difficult to remove are considered fixed contamination. Fixed contamination is not generally as hazardous as loose contamination since the possibility of internal deposition is less. For this reason, maximum permissible surface contamination guides are grouped into fixed and removable levels. Materials contaminated with removable radioactive contamination are considered hazardous both internally and externally but are usually easier to decontaminate.

Material with removable contamination should be packaged or treated to fix the contamination before it is transported to a burial site in order to avoid the spread of contamination. All such material should be buried in an operationally controlled location. Material with fixed contamination may be transported without special packaging and deposited in an isolated waste storage location, provided the area is adequately controlled and posted with radiation warning signs. However, complete burial is eventually necessary in order to provide all the necessary safety.

Low activity contaminated water may usually be released to the soil, provided the activity is not above concentration guides and will not contaminate the natural water table. Methods used to dispose of high-level contaminated water are as follows:

1. Dilute and return to soil.
2. Place in containers and ship for burial.
3. Place in underground storage tanks for decay.

Decontamination efforts should be initiated at the lowest area of contamination and proceed to the highest area of contamination. Recovered material should be placed in containers which can be sealed. Salvageable material can be decontaminated by using numerous agents and methods.

The following is a tabulation of possible decontamination techniques arranged according to the order of the most simple to the most drastic:

1. Tape patches
2. Vacuum cleaning
3. Water

4. Detergents
5. Steam
6. Ultrasonic vibrations
7. Complexing agents
8. Organic solvents
9. Inorganic acids*
10. Acid mixtures*
11. Caustics*
12. Sandblasting*
13. Abrasions*
14. Electrolysis*
15. Flame removal*

*Not to be used on material with critical dimensions.

Appendix I summarizes various decontamination methods.

Personnel Decontamination

To properly decontaminate personnel, it is necessary to first define the areas of contamination by means of proper monitoring techniques. Special emphasis should be placed on the location of any hot spots on the individual. The mildest methods of cleansing should be attempted first, progressing to more harsh methods when necessary. Cleansing methods in order of harshness are as follows:

1. Soap and warm water
2. Mild abrasive soap
3. Complexing solution (carbose)
4. Mild organic acid (citric acid)

After removal of contamination, individuals should take a thorough shower with special attention to washing the hair, hands and fingernails.

In all personnel decontamination procedures every effort should be made to prevent the spread of contamination.

For a more complete survey of personnel decontamination methods see Appendix II.

Land Area Decontamination

Listed below are two principal methods (removal and fixation) which can be employed for decontaminating large land areas.

1. Removal - If future use of the area is necessary, all contaminated debris must be removed to a controlled contaminated waste dump. The area is sprinkled with water to prevent airborne resuspension. Next, the top soil of the contaminated earth is removed to a depth of approximately two to six inches by blading and scraping. Finally, the contaminated earth is removed to the dump site and buried under several feet of uncontaminated earth.

2. Fixation - This method is used in areas where limited future use is anticipated. The area is first sprinkled with water to reduce resuspension of the contaminant. The contaminated top soil is then graded into rows with a triangular cross section (Figure 1), these mounds of earth are normally referred to as "windrows" (Figure 2). The windrows are then sprayed with hot road oil to fix the contaminant in place and to prevent erosion (Figure 3).

Removal of loose contamination on large hard-surfaced areas such as roads, parking lots, etc., is usually accomplished by washing the surface with water under pressure. When the surface is well watered, a mechanical broom can be used to sweep the wash water off the surface and also to scrub contaminated material out of any crevices. Normally, a rinse with a high-pressure fire hose will complete the removal of the loose contaminant. In some cases, only the first wash is necessary. In other cases, the entire scrub-rinse cycle may have to be repeated several times. Control of the run-off on the side of the road must be accomplished by removal or fixation.

Fixation techniques can be classified into four categories as follows:

1. Flooding (85 percent efficient). This leaches the contaminant into the surface.
2. Oiling (89 percent efficient). A rapid cure oil is spread over the contaminated surface.
3. Plowing (98 percent efficient). The land is plowed to a depth of 12 inches to mix and bury the contaminant.
4. Paving (100 percent efficient). The surface is paved with asphalt or concrete to permanently seal the contaminant.

The following list indicates the type of equipment that can be utilized to perform large land area decontamination as previously described:

1. Water tank truck
2. Tractor with a revolving cylindrical steel-bristled brush for street sweeping
3. Rotary action, wet down street sweeper and sweepings collector

4. Street brush and vacuum cleaner machine
5. Water tank truck equipped with a pump, pressure hose, and sprinkling system
6. Road-oil tank truck
7. Tractor and plow
8. Bulldozer
9. Road grader
10. Flat-rack truck
11. Boom truck
12. Earth movers

Decontamination Under Cold Weather Conditions*

The use of water as a decontaminating agent will depend upon the ambient temperature. As the ambient temperature approaches the freezing point for water, decontamination methods become completely ineffective due to the formation of ice. More effective measures would be realized by dry sweeping or vacuum cleaning hard surfaces. If large area hard-packed surfaces are to be decontaminated, commercial street sweepers may prove effective.

If contaminated surfaces are covered with light snow, decontamination is best accomplished through sweeping using hand brooms or a commercial street sweeper, depending on the size of the area to be decontaminated. It is desirable to sweep the material into windrows and employ commercial hauling equipment for removal.

* Joseph C. Maloney, *Radiation Accidents and Emergencies in Medical Research and Industries*, 1965.

Large areas covered with deep snow are usually decontaminated by snow collection and removal with commercial snow plows, road graders, or bull-dozers, and mechanized truck loading machines.

The most difficult area of decontamination in cold weather is that encountered when the contamination is frozen in ice. In this case, the ice must be either removed or melted.

The most desirable objective for decontamination would be to remove all possible traces of contaminants. However, this may not be realistic in any sense of practicality. It is therefore necessary to understand the nature and purpose of decontamination methods and procedures as decontamination can be accomplished adequately regardless of the nature of the operation.

APPENDIX I

Decontamination Methods

Surface	Method	Advantages	Disadvantages
Paint	Water	Most practical method of gross decontamination from a distance. Contamination reduced by approximately 50%.	Protection needed from contaminated spray. Runoff must be controlled. Water under pressure should not be used on a surface covered with a contaminated dust.
	Steam (with detergent if available)	Most practical method for decontaminating large horizontal, vertical, and overhead surfaces. Contamination reduced by approximately 90%.	Same as for water.
	Soapless detergents	Where effective, reduces activity to safe level in 1 or 2 applications.	Mild action.
	Complexing agents,[a] oxalates, carbonates, citrates[b]	Holds contamination in solution. Contamination on unweathered surfaces reduced by approximately 75% in 4 min. Easily stored, nontoxic, noncorrosive.	Requires application from 5-30 min. for effectiveness. Has little penetrating power; hence of small value on weathered surfaces.
	Organic solvents	Quick dissolving action makes solvents useful on vertical and overhead surfaces.	Toxic and flammable. Requires good ventilation and fire precautions.
	Caustics[c]	Minimum contact with contaminated surface. Contamination reduced almost 100%.	Applicable only on horizontal surfaces. Personnel hazard. Not to be used on aluminum or magnesium.
	Abrasion (wet sandblasting)	Complete removal of surface and contamination. Feasible for large-scale operations.	Contaminated sand spread over large area. Method too harsh for many surfaces.
Metal	Water	Contamination reduced by approximately 50%.	Same as for painted surfaces.
	Detergents	Removal of oil or grease films.	Same as for painted surfaces.
	Organic solvents	Stripping of grease.	Same as for painted surfaces.
	Complexing agents,[a] oxalates, carbonates, citrates[b]	Holds contamination in solution.	Difficult to keep in place on any but horizontal surfaces. limited value on weathered porous surfaces.
	Inorganic acids	Fast, complete decontamination.	Good ventilation required; acid fumes toxic to personnel. Possibility of excessive corrosion. Acid mixture cannot be safely heated.
	Acid mixtures	Action of weak acid. Reduces contamination of unweathered surfaces.	Same as for inorganic acids.
	Abrasion (buffers, grinders)	Useful for detailed cleaning.	Follow-up procedured required to pick up powdered contamination.
	Abrasion (wet sandblasting)	Same as for painted surfaces.	Same as for painted surfaces.

Surface	Method	Advantages	Disadvantages
Concrete	Abrasion (vacuum blasting)	Direct removal of contaminated dust.	Contamination of equipment.
	Vacuum cleaning	Same as for vacuum blasting on concrete.	Same as for vacuum blasting on concrete.
	Flame cleaning	Only method of trapping contamination on surface.	Slow and painstaking. Fire and airborne radiation hazard is great.
Brick	Same as for concrete.	Same as for concrete.	Same as for concrete.
Asphalt	Abrasion	No direct contact with surface; contamination may be reduced to safe level.	Residual contamination fixed into asphalt. If road is subject to further contamination, may require recovering.
Wood	Flame cleaning	Sameas for flame cleaning on concrete.	Same as for flame cleaning on concrete.

[a] Another complexing agent would be a solution of 1% ethylenediaminetetracetic acid ("Versene," Sequestrene in water.)

[b] Oxalates, carbonates or citrates may be the ammonium or sodium salts.

[c] Caustics should perferably be trisodium phosphate or sodium sesquicarbonate rather than hydroxides since they are less hazardous.

A PRELIMINARY SUMMARY OF BUILDING-MATERIAL DECONTAMINATION PROCEDURES

Procedures, Equipment, and Additives	Techniques and Surfaces	Advantages	Limitations
1. Vacuuming, using appropriate-capacity industrial-type vacuum cleaner plus suitable exhaust filter. No additives.	Conventional procedure, applies to almost any surface covered by dry loose contaminant.	Retains residue and filters exhaust, reducing aerosols. Often the first step.	Applicable only to dry loose contaminant. Face masks advisable. Slow rate, therefore requires increased manpower and equipment for large areas.
2. Hosing, using hose and nozzle. No additives.	Progress from low to high contamination areas taking advantage of available drainage. Applies to building and floor materials.	Inexpensive procedure for gross decontamination. Minimum protective clothing.	Consumes large volumes of water. Runoff must be controlled.
3. Hosing-hand scrubbing, using hose and nozzle plus floor brushes and mop buckets. Additives: detergents and complexing agents.	Hose, progressing from low to high contamination areas taking advantage of available drainage, then hand scrub with solution containing 1% additive, and follow with hose flush. Applies to building materials.	Effective procedure on dirty and greasy surfaces. Additives easily stored, nontoxic, noncorrosive, minimum protective clothing.	Rate slower than (2). More manpower than (2). Additives use up storage space and not always available.
4. Hot-liquid-jet cleaning--hand scrubbing--hosing, using steam injector, lance, floor brushes and hose, boots and face shields. Additives: detergents and complexing agents.	Educt solution (containing 20% additive) with injector and scrub simultaneously, then follow with hose flush. Applies to building and floor materials.	Same as (3) except for reduction in runoff.	Requires special equipment and steam source. Otherwise same as (3). Steam introduces personnel hazard. Moderate protective clothing required.
5. Steam cleaning, using hose and steam lance, boots and face shields. Additives: detergents and complexing agents.	Additives introduced into flow system to produce 1% solution at lance, proceed as in (2). Applies to building and floor materials; major equipment.	Reduced runoff, low manpower, otherwise same as (3)	Requires steam source. Rate lower than (2). Additives use up storage space and not always available. Steam introduces personnel hazard. Moderate protective clothing required.
6. Stripping--hosing, using drum pump or spray pot, air and liquid hose, lance, hose and nozzle, protective hoods with air lines, boots and rubber gloves. Additives: Sodium, calcium, or potassium, hydroxide containing thickening agents such as starch.	Spray 10 to 20% caustic solution containing thickening agent 24 hour in advance of hose flush, proceed as in (2). Applies to painted surfaces.	Highly effective, removes paint down to base surface. Faster than sandblasting.	Requires special equipment and maximum protective clothing. Hazardous to personnel. Storage and availability problems. Will not remove rust. Cannot be used on aluminum and magnesium surfaces.

Procedures, Equipment, and Additives	Techniques and Surfaces	Advantages	Limitations
7. Paint stripping and hosing, using same equipment as (6) and (8). Additive: cresylic acid.	Same as (6) and (8) except standing time not established. Applies to painted surfaces.	Same as (6) and (8). Removes certain paints not affected by caustics. Can be used on aluminum and magnesium surfaces.	Additive more expensive than caustic, otherwise same as (6).
8. Paint stripping--steam cleaning, using equipment same as (6) except steam hose and lance replace firehose. Additives same as (6).	Spray caustic 24 hour in advance of steam cleaning. Applies to painted surfaces.	Reduce runoff. Otherwise same as (6).	Same as (6).
9. Degreasing--hand scrubbing--rinsing, using spray rig or hand applicators, scrub brushes and water hose or steam line. Additives: emulsifying type degreasers.	Apply degreaser, scrub and rinse (before compound dries) with water detergent solution or steam. Applies to machinery, vehicles, etc.	Removes heavy grease, oil, and dirt deposits not affected by detergents.	Rate slower than (2). More manpower than (2). Additives use up storage space and not always available.
10. Dipping--rinsing, using crane or hoist, dip tank and rinse tank, or hosing or steaming facility. Additives: Same as (6), (7), and (9).	Immerse in suitable additive until grease or paint has been removed and rinse. Applies to portable gear such as pumps,	May be handled remotely, otherwise same as (6), (7), (8), and (9). Solution usually reusable over may applications.	Requires heavy equipment and therefore increased manpower. Limits size of objects decontaminated.
11. Rust removing--rinsing, using swabs, scrub brushers, and water hose or steam line. Additives: inhibited hydrochloric acid.	Coat rust areas with remover, scrub and rinse. Applies to rusty surfaces.	Replaces need for more expensive sandblasting in certain instances.	Hazardous, slow, not so thorough as sandblasting. Requires maximum protective clothing.
12. Sandblasting, using sandblasting machine, air and sand hose, blast hoods with air lines. Additives: Water may be introduced to reduce aerosols.	A standard industrial procedure. Applies to building material such as metal, wood, stone, concrete, etc. Painted and/or rusty surfaces.	Effective, removes rust as well as paint.	Extremely slow, expensive, creates aerosol hazard. Maximum protective clothing.
13. Vacuum blasting using vacuum blasting machine. Additives: special abrasive shot.	Conventional procedures. Applies to building material such as metal, wood, stone, concrete, etc. Painted and/or rusty surfaces.	Vacuum residue, reducing aerosols, otherwise same as (2). Recycles and reuses abrasive.	Slow, awkward for areas other than horizontal. Face masks advisable. Auxiliary exhaust filters required.
14. Floor refinishing using floor-resurfacing machines. No additives.	Planes off layer of material through action of rotary cutting tools. Applies to wood, concrete, brick, etc.	Only means short of demolition in some cases.	Requires follow-up method to retrieve residue. Slow. Surface destructive. Aerosol hazard. Face masks required.

CONTAMINABILITY TO FISSION PRODUCTS

	<10%	10-30%	30-70%	>70%
Polythene, Teflon, and Saran	All normal conditions			
Water-repellant paints (unweathered)	-----	When oxidized or covered with foreign deposits		
Formaldehyde resins	-----	Most solutions		
Glass (plate)	-----	Aged fission products		
Lead	With Ba^{140} in HCl	Surface scarred	-----	With $H_2P^{32}O_4$-, aged fission products
Polished stainless steel (type 147)	Dilute acid solutions of carrier-free P^{32}, Ba^{140}, and I^{131}	-----	Aged fission products in dilute acid	
Unpolished stainless steel	Unblemished	Blemished		
Structural steel	-----	Dilute acid solutions	With P^{32}	
Glazed-tile surfaces	-----	When coated with laboratory or industrial film deposits		
Best grades of floor tile	-----	-----	Floor tiles in good condition	Tiles scarred or scratched (worn)
Plastic spray coats	Dried without pinholes	Pinholes on evaporation of solvent		
Alberene stone	-----	Impregnated with vinyl resins	Impregnated with formaldehyde or phenolic resins	Untreated
Transite	-----	-----	-----	Untreated, contaminated with most acid solutions
Concrete	Painted, unworn	Painted, worn	Smooth but not impregnated. Exposed to insoluble hydroxides under alkaline conditions	Untreated, contaminated with most acid solutions

EFFECT OF RADIOACTIVITY LEVEL ON CONTAMINATION

Level	<1 μc	1 μc to 1 mc	1 mc to 1 curie	>1 curie
Features of technique	Quantitative technique 99.9% control, aseptic precautions	99.999% control segregation of equipment to avoid cross contamination, avoid spattering and solution losses	99.999999% control, enclosed operations, either equipment or area	Extreme control, complete enclosure, buffer areas
Special features of laboratory and equipment, in addition to aseptic precautions	Ordinary laboratory	Radiochemical hood desirable, storage and cleaning facilities duplicated, protect bench tops	Radiochemical hood mandadatory, dry boxes advisable. Cleaning ducts, special waste disposal. High-efficiency hood and dry-box filters	Decontaminable ducts and drains, dry box or isolated cubical with high-efficiency filters
Special problems	Protection of experiments ments in vicinity of higher-level operations	Absorption of high specific activity material; hand contamination and second-order transfer	Decontaminatable surfaces; accumulation (long-lived activity); ventilation, protection against accidents important	Gas, liquid, and solid waste storage or disposal
Examples	Tracer-level experiments with β-counting	Tracer-level experiments with γ-activity counting; preparation of stocks of β-tracer, process tracer application. Isolation of a radionuclide which is a constituent of a mixture	Preparation of stocks of γ-tracer, high-level C^{14} synthesis, therapeutic work. Isolation of a radionuclide which is a minor constituent of a mixture	Radioactive sources for radiography, etc.

Tompkins, P.C., and H. A. Levy, Impact of Radioactivity on Chemical Laboratory Techniques and Design, *Ind. Eng. Chem.*, vol. 41, p. 228, 1949.

GENERAL REAGENTS FOR DECONTAMINATION

Reagent Type	Typical Representative	Where Used	Remarks
Mineral acids	HCl, HNO_3, H_2SO_4	Metals, glass, plastics, paint	10% solutions for dilute reagents. Destructive to surface. Usually most efficient reagents if materials can tolerate their use
Strong oxidizing solutions	Chromic acid cleaning solution	Glass, metals	Laboratory cleaning agent. Last-resort treatment. Often used for Pu
Trisodium phosphate	-----	Glass, paints, plastics	10% solution. Often used hot. Removes wax and is hard on paint
Fluoride	$(NH_4)_2SiF_6$	Glass, porcelain, and other silicone materials	0.1 - 1% solution
Complexing agents	Sodium citrate, versene	All materials	1-10% solutions. Efficiency variable and pH-dependent. Often preferred choice for general use
Detergents	Household or commercial cleaning detergents such as Tide	All materials	Efficiency variable. Choice sensitive to water properties as well as materials and contaminants used with scrubbing

SOURCES OF RADIOACTIVE CONTAMINATION

1. Chemical reactions leading to the loss of a gas.
2. Evaporation of a liquid.
3. Aeration of liquid.
4. Liquid transfers of all kinds.
5. Grinding or manipulation of a solid.
6. Recoil from radioactive disintegration (especially with alpha emitters).
7. Absorption on surfaces (especially high-specific-activity material).

Revised: January 1978

APPENDIX II

PERSONNEL DECONTAMINATION

Method*	Surface	Action	Technique	Advantages	Disadvantages
Soap and water	Skin and hands	Emulsifies and dissolves contaminate.	Wash 2-3 minutes and monitor. Do not wash more than 3-4 times.	Readily available and effective for most radioactive contamination.	Continued washing will defat the skin. Indiscriminate washing of other than affected parts may spread contamination.
Soap and water	Hair	Same as above.	Wash several times. If contamination is not lowered to acceptable levels, shave the head and apply skin decontamination methods.		
Lava soap, soft brush, and water	Skin and hands	Emulsifies, dissolves, and erodes. erode the skin. Apply	Use light pressure with heavy lather. Wash for 2 minutes, 3 times. Rinse and monitor. Use care not to scratch or lanolin or hand cream to prevent chapping.	Same as above.	Continued washing will abrade the skin.
Tide or other detergent (plain)	Same as above.	Same as above.	Make into a paste. Use with additional water with a mild scrubbing action. Use care not to erode the skin.	Slightly more effective than washing with soap.	Will defat and abrade skin and must be used with care.
Mixture of 50% Tide and 50% cornmeal	Skin and hands.	Emulsifies, dissolves, and erodes.	Make into a paste. Use with additional water with a mild scrubbing action. Use care not to erode the skin.	Slightly more effective than washing with soap.	Will defat and abrode sken and must be used with care.
5% water solution of a mixture of 30% Tide, 65% Calgon, 5% Carbose (carboxymethyl cellulose)	Same as above.	Same as above.	Use with water. Rub for a minute and rinse.	Same as above.	Same as above
A preparation of 8% Carbose, 3% Tide, 1% Versene, and 88% water homogenized into a cream.	Same as above.	Same as above.	Use with additional water. Rub for 1 minute and wipe off. Follow with lanolin or hand cream.	Same as above.	Same as above.

*Begin with the first listed method and then proceed step by step to the more severe methods, as necessary.

PERSONNEL DECONTAMINATION--Continued

Method*	Surface	Action	Technique	Advantages	Disadvantages
Titanium dioxide paste. Prepare paste by mixing precipitated titanium dioxide (a very thick slurry, never permitted to dry) with a small amount of lanolin. If not successful, go on to the next step.	Skin, hands, and extremities. Do not use near face or other body openings.	Same as above.	Work the paste into the affected area for 2 minutes. Rinse and wash with soap and warm water. Monitor.	Removes contamination lodged under scaly surface of skin. Good for heavy surface contamination of skin.	If left on too long will remove skin.
Mix equal volumes of a saturated solution of potassium permanganate and 0.2 N sulfuric acid. (Saturated solution of $KMnO_4$ is 6.4 grams per 100 ml of H_2O.) Continue with next step.	Skin, hands, and extremities. Do not use near face or other openings.	Dissolves contaminant absorbed in the epidermis.	Pour over wet hands, rubbing the surface and using handbrush for not more than 2 minutes. Rinse with water.	Superior for skin contamination. May be used in conjunction with titanium oxide.	Will remove a layer of skin if in contact with the skin for more than 2 minutes.
Apply a freshly prepared 5% solution of sodium acid sulfite. (Solution made by dissolving 5 gm of $NaHSO_3$ crystals in 100 ml distilled water.)	Same as above.	Removes the permanganate stain.	Apply in same manner as above. Apply for not more than 2 minutes. The above procedure may be repeated. Apply lanolin or hand cream when completed.		Same as above
Flushing	Eyes, ears, nose, and mouth	Physical removal by flushing.	Roll back the eyelid as far as possible, flush with large amounts of water. If isotonic irrigants are available, obtain them without delay. Apply to eye continually and then flush with large amounts of water. (Isotonic irrigant [0.9% NaCl solution]: 9 grams NaCl in beaker, fill to 1000 cc with water.) Can be purchased from drug suppliers, etc. Further decontamination should be done under medical supervision.	If used immediately will remove contamination. May also be used for ears, nose, and throat.	When using for nose and mouth, contaminated individual should be warned not to swallow the rinses.

Method*	Surface	Action	Technique	Advantages	Disadvantages
Flushing	Wounds	Physical removal by flushing.	Wash wound with large amounts of water and spread edges to stimulate bleeding, if not profuse. If profuse, stop bleeding first, clean edges of wound, bandage, and if any contamination remains, it may be removed by normal cleaning methods, as above.	Quick and efficient if wound not severe.	May spread contamination to other areas of body if not done carefully.
Sweating	Skin of hands and feet	Physical removal by sweating.	Place hand or foot in plastic glove or booty. Tape shut. Place near source of heat for 10-15 minutes or until hand or foot is sweating profusely. Remove glove and then wash using standard techniques. Or gloves can be worn for several hours using only body heat.	Cleansing action is from inside out. Hand does not dry out.	If glove or booty is not removed shortly after profuse sweating starts and part washed with soap and water immediately, contamination may seep into the pores.

AREA AND MATERIAL DECONTAMINATION

Method*	Surface	Action	Technique	Advantages	Disadvantages
Vacuum cleaning	Dry surfaces	Removes contaminated dust by suction.	Use conventional vacuum technique with efficient filter.	Good on dry, porous surfaces. Avoids water reactions.	All dust must be filtered out of exhaust. Machine is contaminated.
Water	All nonporous surfaces (metal, painted, plastic etc.).	Dissolves and erodes.	For large surfaces Hose with high-pressure water at an optimum distance of 15 to 20 feet. Spray vertical surfaces at an angle of incidence of 30° to 40°; work from top to bottom to avoid recontamination. Work upwind to avoid spray. Determine cleaning rate experimentally, if possible; otherwise, use a rate of 4 square feet per minute.	All water equipment may be utilized. Allows operation to be carried out from a distance. Contamination may be reduced by 50%. Water equipment may be used for solutions of other decontaminating agents.	Drainage must be controlled. Not suitable for porous materials. Oiled surfaces cannot be decontaminated. Not applicable on dry contaminated surfaces (use vacuum); not applicable on pourous surfaces such as wood, concrete, canvas, etc. Spray will be contaminated.

ıd*	Surface	Action	Technique	Advantages	Disadvantages
	All surfaces	Dissolves and erodes.	For small surfaces Blot up liquid and hand-wipe with water and appropriate commercial detergent.	Extremely effective if done immediately after spill and on nonporous surfaces.	Of little value in the decontamination of large areas, longstanding contaminants and porous surfaces.
	Nonporous surfaces (especially painted or oiled surfaces).	Same as above.	Work from top to bottom and from upwind. Clean surface at a rate of 4 square feet per minute. The cleaning efficiency of steam will be greatly increased by using detergents.	Contamination may be reduced approximately 90% on painted surfaces.	Steam subject to same limitations as water. Spray hazard makes the wearing of water-proof outfits necessary.
Detergents	Nonporous surfaces (metal, painted, glass, plastic, etc.).	Emulsifies contaminant and increases wetting power of water and cleaning efficiency of steam.	Rub surface 1 minute with a rag moistened with detergent solution then wipe with dry rag; use clean surface of the rag for each application. Use a power rotary brush with pressure feed for more efficient cleaning. Apply solution from a distance with a pressure proportioner. Do not allow solution to drip onto other surfaces. Mist application is all that is necessary.	Dissolve industrial film and other materials which hold contamination. Contamination may be reduced by 90%.	May require personal contact with surface. May not be efficient on longstanding contamination.
Complexing agents	Nonporous surfaces (especially unweathered surfaces; i.e., no rust or calcareous growth).	Forms soluble complexes with contaminated material.	Complexing agent solution should contain 3% (by weight) of agent. Spray surface with solution. Keep surface moist 30 minutes by spraying with solution periodically. After 30 minutes, flush material off with water. Complexing agents may be used on vertical and overhead surfaces by adding chemical foam (sodium carbonate or aluminum sulfate).	Holds contamination in solution. Contamination may be reduced by 75% in 4 minutes on unweathered surfaces. Easily stored; carbonates and citrates are nontoxic, noncorrosive.	Requires application for 5 to 30 minutes. Little penetrating power; of small value on weathered surfaces.

Method*	Surface	Action	Technique	Advantages	Disadvantages
Organic solvents	Nonporous surfaces (greasy or waxed surfaces, paint or plastic finishes, etc.)	Dissolves organic materials (oil, paint, etc.).	Immerse entire unit in solvent or apply by wiping procedure (see Detergents).	Quick dissolving action. Recovery of solvent possible by distillation.	Requires good ventilation and fire precautions. Toxic to personnel. Material bulky.
Inorganic acids	Metal surfaces (especially with porous deposits; i.e., rust or calcareous growth); circulatory pipe systems.	Dissolves porous deposits.	Use dip-bath procedure for movable items. Acid should be kept at a concentration of 1 to 2 normal (9 to 18% hydrochloric, 3 to 6% sulfuric acid). Leave on weathered surfaces for 1 hour. Flush surface with water, scrub with a water-detergent solution, and rinse. Leave in pipe circulatory system 2 to 4 hours; flush with plain water, a water-detergent solution, then again with plain water.	Corrosive action on metal and porous deposits.	Personal hazard. Wear goggles, rubber boots, gloves and aprons. Good ventilation required because of toxicity and explosive gases. Acid mixtures should not be heated. Possibility of excessive corrosion if used without inhibitors. Sulfuric acid not effective on calcareous deposits.
Acid mixtures: hydrochloric, sulfuric, acetic, citric acids.	Nonporous surfaces (especially with porous deposits); circulatory pipe systems.	Dissolves porous deposits.	Same as for inorganic acids. A typical mixture consists of 0.1 gal. hydrochloric acid, 0.2 lb. sodium acetate and 1 gal. water.	Contamination may reduced by 90% in 1 hour (unweathered surfaces). More easily handled then inorganic acid solutions.	Weathered surfaces may require prolonged treatment. Same safety precautions as required for inorganic acids.
Caustics: lye (sodium hydroxide), calcium hydroxide, potassium hydroxide	Painted surfaces (horizontal).	Softens paint (harsh method).	Allow paint remover solution to remain on surface until paint is softened to the point where it may be washed off with water. Remove remaining paint with long-handled scrapers. Typical paint remover solution: 10 gal. water, 4 lb. lye, 6 lb. boiler compound, 0.75 lb. cornstarch.	Minimum contact with contaminated surfaces. Easily stored.	Personal hazard (will cause burns). Reaction slow; thus, it is not efficient on vertical or overhead surfaces. Should not be used on aluminum or magnesium.
Trisodium phosphate	Painted surfaces (vertical, overhead).	Softens paint (mild method).	Apply hot 10% solution by rubbing and wiping procedure (see Detergent).	Contamination may be reduced to tolerance in one or two applications.	Destructive effect on paint. Should not be used on aluminum or magnesium.

AREA AND MATERIAL DECONTAMINATION--Continued

Method*	Surface	Action	Technique	Advantages	Disadvantages
Abrasion	Nonporous surfaces.	Removes surface.	Use conventional procedures, such as sanding, filing, and chipping; keep surface damp to avoid dust hazard.	Contamination may be reduced to as low a level as desired.	Impracticable for porous surfaces because of penetration by moisture.
Sandblasting	Nonporous surfaces.	Removes surface.	Keep sand wet to lessen spread of contamination. Collect used abrasive or flush away with water.	Practical for large surface areas.	Contamination spread over area must be removed. Contaminated dust is personnel hazard.
Vacuum blasting	Porous and nonporous surfaces.	Removes surface; traps and controls contaminated waste.	Hold tool flush to surface to prevent escape of contamination.	Contaminated waste ready for disposal. Safest abrasion method.	Contamination of equipment.

Formulas Used for Decontamination of Personnel

	Formula		Use
1.	Soap and shampoo.	1.	Preliminary wash. Scrub well.
2.	Abrasive soap (Lava).	2.	Use with water and brush.
3.	50% cornmeal plus 50% detergent (Tide) plus water to a paste.	3.	Scrub well with brush.
4.	Solid mixture of 30% detergent (Tide), 65% Calgon and 5% Carbose (carboxymethyl cellulose)	4.	Prepare a 5% water solution of this mixture for spot cleaning with swabs or for use on the hands.
5.	8% Carbose, 3% detergent, 1% Versene, 8% water. Homogenize into a cream.	5.	Use without additional water. Rub into skin 3 to 5 min. and wash off with water. Use only in stubborn cases since Versene may increase the absorption of the radioelement.
6.	Mechanic's waterless handcleaning cream.	6.	Good for grease. Less irritating than scrubbing methods.
7.	Lanolin hand cream.	7.	Use between washes when skin becomes irritated from heavy scrubbing.
8.	Saturated solution of potassium permanganate followed by sodium bisulfite to remove the stain.	8.	Kills outer layers of skin. Should be done only under a doctor's supervision. Used only as a last-resort method.

SECTION 24

ACCIDENT RESPONSE SYSTEMS

Within the Department of Energy (DOE), the Department of Defense (DOD), and several other Federal agencies such as the Environmental Protection Agency-(EPA), and Coast Guard, plans and procedures have been established for responding to accidents involving radioactive materials. The DOE and DOD accident response system are of primary interest. Other agencies will be covered in the discussion on the Interagency Radiological Assistance Plan.

Members of radiological emergency assistance teams should be familiar with all aspects of emergency planning and operations. The general principles of emergency planning will be presented, followed by a short history of the circumstances that led into the DOE Radiological Assistance Plan. Additionally, the DOE, DOD, and interagency plans for radiological emergency operations will be discussed.

Planning Emergency Operations

Any organization dealing with radioactive material should constantly evaluate all phases of its operation. After all normal safety procedures have been incorporated, the next step is to consider the possibilities of accidents. The fact that safety procedures, conscientiously applied, can never be an absolute "accident prevention" guarantee should always be borne in mind. Unfortunately, most serious accidents have resulted from work believed to be conducted according to safe procedures; for example, the plutonium solution criticality at Los Alamos and the SL-1 criticality accident at Idaho Falls. The advantages of planning for recovery from the maximum credible accident cannot be overemphasized. Potential accident

conditions are often difficult to foresee, but preparing for the worst, as well as for lesser incidents, will permit prompt application of adaptive measures for most situations with a minimum of "time without control." Many organizations, although capable of handling accidents occurring in normal industrial operations, are sometimes inadequately prepared to meet emergencies involving radioactive materials. Coordinated response plans should be established with capable neighboring organizations which might be needed in a serious radiological emergency. These organizations should include local fire and police departments, medical emergency facilities, and local private physicians as well as hospitals.

Mutual aid arrangements established with neighboring facilities and organizations can provide for immediate assistance. Such assistance could be obtained directly and would not require action by a coordinating response agency. While this would not remove the responsibility for necessary reports and other obligations, a mutual aid arrangement provides a more rapid and effective response in emergencies.

Development of the DOE Radiological Assistance Plan

The atomic energy program began as a civilian program when the Atomic Energy Act of 1946 was enacted by Congress. Over the years, the laboratories and plants operated for the Atomic Energy Commission (now DOE) have developed emergency plans for the protection of personnel and facilities. Included in these plans were the training and equipping of personnel who would act as emergency teams whenever needed. From time to time, help was given to private organizations and individuals who become involved in incidents with radioactive materials and came to the AEC for assistance.

Special provisions were made for response in the case of accidents involving nuclear weapon components. These provisions consisted of emergency plans and specially qualified radiological safety teams. The AEC Albuquerque Operations Office and the Air Force Special Weapons Project (AFSWP) at Albuquerque set up these specialized teams. Under arrangements for mutual cooperation, the military and AEC teams worked together during weapons accident emergencies. Later these arrangements were formalized in the 1958 AEC-DOD agreement.

The AEC Licensing and Regulation program was initiated by a 1954 revision to the Atomic Energy Act of 1946. Through the licensing program the number of users of radioactive material began to increase all over the United States. The atomic energy program also continued to expand. In short, the entire atomic energy industry was developing more and more with each passing year. Along with this development, there was an increasing awareness of the possibility for accidents to occur with radioactive materials whether privately or Federally controlled.

In 1957, the General Manager of the Atomic Energy Commission decided that there should be a universal plan developed to cope with accidents involving radioactive material. One aspect of early planning was to formalize the arrangement between the Atomic Energy Commission and the Department of Defense to coordinate the necessary capabilities to cope with accidents involving atomic weapons. At the same time, a plan was initiated whereby the AEC could provide assistance, as in the joint agreement with the DOD, or cover accidents involving AEC operations, or respond to requests for assistance from others. The Energy Reorganization Act of 1974 has assigned all these responsibilities to ERDA (now DOE).

The JNACC Agreement

The AEC and DOD signed an agreement effective February 27, 1958, entitled *Joint Department of the Army, Navy, Air Force, and Atomic Energy Commission Agreement of General Areas of Responsibility and Procedures Applicable to the Prompt, Effective, and Coordinated Response to Accidents Involving Nuclear Weapons.* Under this agreement, the AEC and DOD officially joined their forces to form a pool of capabilities in the areas of radiation monitoring, technical disciplines, medical advice, public relations, and nuclear weapons safety. This agreement was revised and is now entitled the *Joint Department of Defense and Atomic Energy Commission Agreement in Response to Accidents Involving Radioactive Material* dated May 9, 1966.

The joint AEC-DOD agreement provided for establishing a Joint Nuclear Accident Coordinating Center (JNACC) at Albuquerque, New Mexico. The mission of JNACC is to provide a centralized agency to exchange and maintain information concerning DOE and DOD radiological assistance capabilities. It also coordinates DOE-DOD assistance activities when called upon in connection with radiation accidents. The principal JNACC functions are as follows:

1. Maintain current information as to the DOD and DOE radiological emergency team capabilities.
2. Receive notifications of accidents and requests for assistance.
3. Receive reports concerning the activities of emergency teams dispatched to the scene of an accident.
4. Request assistance from the appropriate DOD or DOE organization as may be necessary.
5. Provide information concerning accidents from DOD commands and for the DOE.

6. Obtain such information as is available regarding radioactive material involved in an accident for relay to the accident scene.
7. Refer inquiries from the public to the military service or DOE office having the primary responsibility for command of the emergency operations.
8. Furnish the essentials of the JNACC procedures to the DOD and DOE.

This list strongly emphasizes the joint coordinating function of JNACC.

JNACC has no authority to direct emergency operations or to order a team from a particular DOD or DOE installation to the scene of an accident. JNACC has two offices located at Sandia Base, Albuquerque, New Mexico. One office is in the Field Command Headquarters of the Defense Nuclear Agency. These two offices have special telephone lines on which they receive reports of radiation accidents and requests for emergency assistance. When the incident or accident involves nuclear weapons or weapons components, the first office to learn about it immediately calls the other and establishes contact for further coordination. Then, if the assistance of the DOE or DOD is required, requests are made through the appropriate channels.

For example, if a military installation has an accident involving a nuclear weapon, the DOE is immediately informed about it through JNACC. It may develop that the military service directly involved in the accident would like assistance from the Department of Energy and its contractors. In this case, the request would be made to JNACC and then communicated to the DOE. The DOE would then, with the cooperation of the military, send personnel and equipment to the scene of the accident. In order to facilitate immediate action, the DOE Albuquerque Operations Office maintains a team of weapons

experts whose members are constantly ready for dispatch to any place in the United States or to United States installations in other countries.

The DOE Radiological Assistance Plan

At the time that the JNACC agreement was put into effect, there was also work being done on an AEC (now DOE) Radiological Assistance Plan for the Headquarters and Field Offices of the Commission. This plan was issued in June of 1958 and provided the policy and implementing instructions for the AEC offices. The plan not only included the basic procedures for covering weapons accidents, but also provided for emergency operations to deal with incidents at AEC facilities, licensee establishments, and other agencies that might request aid from the AEC.

Under the Radiological Assistance Plan, eight Field Offices were assigned geographical areas of responsibility for radiological assistance. Included in these regions are the Canal Zone, Puerto Rico, the Virgin Islands, Hawaii, and Alaska. Under this policy, anyone involved with an incident, in which radioactive materials are believed to be involved, may request assistance from the DOE. The kind and quantity of assistance provided will depend upon evaluation of the initial request and the circumstances surrounding the incident. In some incidents, adequate assistance is provided by giving technical advice over the telephone; in other incidents, it may be necessary to dispatch DOE emergency personnel and equipment to the scene. On the other hand, the request may be referred to another agency to take the necessary action.

Requests for assistance may be made to any DOE or military facility. However, within the DOE, the primary responsibility for regional plans and emergency

assistance capabilities have been assigned to the eight DOE offices. These offices, in regional number order, are the following: Brookhaven Area office, Oak Ridge Operations, Savannah River Operations, Albuquerque Operations, Chicago Operations, Idaho Operations, San Francisco Operations, and Richland Operations.

Requests for DOE assistance may also be made to military installations. These requests are referred to the appropriate DOE office directly or through JNACC. As previously mentioned, the DOE Albuquerque Operations Office is responsible for DOE-JNACC operations and Albuquerque is also responsible for DOE plans, procedures, and coordination of nuclear weapons emergency response operations. The other DOE Field Offices will respond to weapons incidents in accordance with the Albuquerque Operations Office guidance.

Each DOE Operations office has an emergency telephone number that may be called by anyone who wishes to request assistance or to report an incident. Since these numbers are answered 24 hours a day, they are the preferred offices to be called. However, it is satisfactory if the requester contacts the nearest DOE office known to him.

Within the Department of Energy, the telephone number listed for the Albuquerque Operations Office is also the DOE-JNACC number. Through the JNACC it can be learned if DOE facilities are involved with radiation emergencies, what team capabilities are available, and which of them are actively engaged in an emergency operation. It should be noted that, even though there are organized teams made up of trained personnel, all of these personnel are DOE and contractor employees who serve on radiological assistance teams in addition to their regular jobs.

The Interagency Radiological Assistance Plan (IRAP)

The implementation of the June 1958 Radiological Assistance Plan included a provision for meeting with other Federal agency representatives and explaining the AEC plan to them. When the meeting was held, it was proposed that consideration should be given to an interagency plan with the idea of providing for the use of all available Federal capabilities in the event of a serious peacetime radiation accident. Therefore, a committee was formed and in July, 1961, a plan had been approved by 13 participating Federal agencies.

As of April, 1975, Federal agencies signatory to the Interagency Radiological Assistance Plan were the following:

- Department of Agriculture
- Department of Commerce
- Department of Defense
    - Defense Civil Preparedness Agency
- Department of Health, Education, and Welfare
- Department of Labor
- Department of Transportation
- Energy Research and Development Administration
- Environmental Protection Agency
- Interstate Commerce Commission
- National Aeronautics and Space Administration
- Nuclear Regulatory Commission
- Postal Service

Other interested Federal agencies can become signatory by declaring their approval of and agreement to the provisions of the Interagency Radiological Assistance Plan. Since copies of the Interagency Radiological Assistance Plan are available, the details of this plan will not be discussed. However, it should be noted that the primary purposes of the plan are: first, to supply effective assistance to anyone requesting it in the case of an incident involving radioactive materials; second, to provide for the coordination of Federal, state, and local radiological incident assistance operations; and third, to encourage the development of state and local radiological assistance capabilities.

Under this plan, an Interagency Committee on Radiological Assistance is established comprising an authorized representative of each Federal agency participating in the plan. This committee is responsible for obtaining agency approvals of IRAP policy, interpretations of the policy, and changes in the provisions of the plan. It also assures the respective agencies that the plan is carried out in a manner consistent with Federal statutes and executive orders that are applicable to radiological emergency activities. The Atomic Energy Commission (now DOE) was designated the agency responsible for general management and administration of the plan. This responsibility is carried out through a national coordinating office at DOE Headquarters and Regional Coordinating Offices at DOE Operations Office. Other Federal agencies have established coordinating offices at the national and regional or lower levels. However, these offices serve only to coordinate their own agency's participation in the Interagency Plan. Therefore, the offices of other agencies do not have Interagency Plan administrative responsibilities like those assigned to the DOE offices.

There are other agencies that have response systems for handling radi emergencies. Among these are the EPA Plan for responding to radiolog incidents; the part of the U.S. Coast Guard Search and Rescue Plan th covers radiological emergencies involving navigable waters and the in plans of the Navy, Air Force, and Army. The Department of Transporta has a response system to be followed in the event of transportation ac dents involving the railways or highways used for transporting radioac materials. These (and other systems) are not superseded by the Intera Plan but instead become an integral part of the Interagency Plan.

In addition to the Federal agencies, some states have implemented deta radiation emergency plans and many others are working on such plans. plans include an emergency team response capability complete with inst tation, transportation, and communication, and in some cases laborator facilities that can be used to cope with radiation hazards resulting f accidents. The Interagency Plan expects to include procedures and arr ments to link the Federal agency operations with those of state and lo agencies.

Emergency Response Operations

When the responsible regional coordinating office receives information cerning an accident, or has been asked for assistance, the first respon to obtain as much information as possible from the requester or the rep of the incident. The more information that can be obtained from the fi call, the more effective the response will be. In every case, the mini information required will be the name and address of the caller, the te phone number at which he can be reached, the exact location of the inci

who has been called in on the emergency, what the caller believes the nature of the radioactive material is, and any other information that might be needed in order to respond appropriately to the request for assistance.

If it is believed that the incident involves a nuclear weapon, weapon component or military radioactive material, the JNACC must be immediately notified. In that case, JNACC officials would advise what action is to be taken by the regional coordinating office. The coordinating office will not be required to report to the JNACC unless an emergency team is dispatched. In that event, the JNACC is told of the action so that it can be kept informed on the status of emergency team availability within the areas of the regional offices. Depending upon the coordinating offical's evaluation of the assistance needed, the necessary emergency response will be initiated.

The capabilities at the DOE team sites vary, but in general they may include radiation monitoring, environmental sampling and monitoring, decontamination advice and assistance if needed, medical advice, laboratory services, specialists in nuclear weapons safety, and other safety and health protection experts. All DOE team members carry identification cards for identification purposes.

As soon as possible, it is determined whose radioactive material is involved. If the material belongs to a military service, the primary responsibility for emergency operations at the scene of the incident belongs to that military service. In the event that an DOE team is dispatched and arrives at the scene prior to a military team, the DOE team captain takes immediate charge of emergency operations. This responsibility is transferred to the appropriate military authority upon his arrival. If the material is in the

possession of a privately owned organization or civilian agency, the emergency control at the scene would be their responsibility and the D team would be entirely in an assistance and advisory capacity. If the material belongs to an NRC licensee, the DOE team would be responsible for emergency operations until a representative of the licensee arrive at the scene and assumed responsibility. If the material is in the po sion of the DOE, then the responsibility for emergency operations clea belongs to the DOE. It should be understood though that this responsi does not carry any privilege of command over civil authorities or priv persons at the scene of an incident. The cooperation of state and loc fire, police, and other civil authorities is always asked for and has always been received. However, no DOE team has authority beyond that w is necessary to control the actual material involved. This approach to need to establish the authority to direct emergency operations at the s has been quite successful in actual experience.

In general, the mission of the emergency assistance team is as follows:

<u>Define the Radiological Problems</u>...Obtain all information concerni the incident, the material, and the identification of persons who have been associated or involved with the incident.

<u>Control the Radiological Problems</u>...Minimize the immediate hazards to health and safety by carrying out such radiation monitoring and other emergency procedures as are necessary to bring the situation under control.

Document and Report Conditions...Document information which can be given to officials and which can be released to the public. Report conditions and significant team actions to the appropriate Regional Coordination Office or other DOE offices.

Assist in Restoration of Normal Operations when Requested...As soon as the situation has been brought under control, the responsibility for post-emergency operations rests with the persons or agency having legal accountability for the radioactive material that was involved. However, DOE radiological emergency assistance would not be withdrawn from the incident scene until there was reasonable assurance that appropriate remedial action was being taken, and that the public health and safety would be protected. It may be recognized that the emergency response procedures of DOE teams from the various installations may differ. However, the plans and procedures for each DOE radiological assistance region and for the teams of each individual installation are periodically reviewed and evaluated to determine that they meet the basic requirements of the DOE Radiological Assistance Program.

SECTION 25

RADIOLOGICAL ACCIDENTS

The control and handling of nuclear accidents is a relatively new field and, as such, is in a continual process of evolution. As in many new fields, experience is an excellent teacher and much can be learned from reviewing the accidents that have occurred. By observing accident histories mistakes can be avoided in the handling of subsequent accidents and improved means of accident control can be implemented. The following accident histories are offered for this purpose:

The Los Alamos Scientific Laboratory Criticality Accident, 1946

A scientist was demonstrating a criticality experiment to another physicist. Six other observers were in the same room. Basically, the planned experiment consisted of surrounding an amount of fissionable material with two hemispheres of beryllium. Fissionable material was placed in one hemisphere and the other hemispherical section of beryllium was slowly brought down until a point was reached that was just sub-critical. A screwdriver was used as a lever to lower the upper hemisphere and to hold it in place. The whole assembly was steadied by the operator keeping one hand on top of the hemisphere.

The accident occurred when the two hemispheres were approximately one inch apart. The screwdriver apparently slipped, the upper hemisphere fell, causing a complete reflecting sphere with the fissionable material inside. A blue flash and heat wave were noticed. The physicist conducting the experiment pulled the two hemispheres apart with his hands. The exposure doses were determined from film badges located around the room. Personnel noted

their positions at the time of criticality (Figure 1). The dose to the man performing the experiment was estimated to be between 10,000 and 15,000 rem to the hands and approximately 5,000 rem to the whole body. He died nine days after exposure. The dose to the second scientist caused clinical injury. The other six employees exceeded the established daily limit, but had no observable permanent damage.

The prime cause for this incident was improper equipment and operating procedures. New remote handling devices were developed as a result of this accident.

The Windscale Accident, October 8-12, 1957

The reactor located at Windscale, England, was one of two air-cooled, graphite moderated, natural uranium reactors used for plutonium production. At the time of the accident, experiments were being performed which released stored energy from the irradiated graphite by annealing the material. Normally, this process releases energy at a controlled rate; but, this time it was released at an excessive rate in parts of the core. The result was a slow burning process in the core which went undetected for a period of four days (October 8-12, 1957) due to insufficient instrumentation. The release of activity was finally detected by an air sampler about one-half mile downwind from the reactor stack. The air sample read approximately 3000 dpm/m^3, or about ten times the normal background radiation level.

Visual inspection revealed that some of the fuel elements were ruptured and were glowing red. Since the fuel elements could not be discharged from the reactor to shut it down, the reactor was finally cooled by flooding with water.

Steps were immediately taken to determine the external dose and the isotope quantities ingested by the population as a result of the release. It was found that the maximum external dose that could have been received by a person remaining in the area of maximum exposure for one week was in the range of 30-50 mR (Figure 3). Under the circumstances, this was considered negligible.

The average air contamination, as determined from 12,000 samples, reached a peak at 4.5×10^{-7} µCi/ml, with an average concentration of 4.5×10^{-9} µCi/ml (Figure 2). This concentration is 50 per cent greater than the International Committee on Radiation Protection Standard for continuous exposure to ^{131}I. It was subsequently found that the concentrations of ^{89}Sr and ^{90}Sr in milk and food were below maximum permissible levels.

As a result of the accident, the following amounts of activity were estimated as being released to the atmosphere:

Isotope	Curies
^{131}I	20,000
^{137}Cs	600
^{89}Sr	80
^{90}Sr	9

The sizeable release of ^{131}I presented the greatest hazard due to the large dairy industry in the area. A full-scale milk sampling program was immediately undertaken. Persons living as far as 24 miles downwind from the reactor were scanned with a scintillation detector to determine their internal doses of ^{131}I. The highest dose in children was 16 rad while the highest adult dose was 9.5 rad.

After gamma spectrometric analyses were completed, it was found that the amount of ^{131}I in milk exceeded 0.1 μCi/l in an area of 200 square miles southeast of the reactor. The sale of some milk was restricted and remained so until November 23, 1957.

Many lessons were learned from this incident. By far, the most important of these is that very few local health physics organizations are large enough to be capable of handling an accident of this magnitude. During the Windscale incident, resources were pooled from all over the United Kingdom.

It was also found that, as far as ^{131}I is concerned, a level of 0.1 μCi/l in milk will result in a thyroid dose of 20 rem or more. An indirect means of estimating the amount of ^{131}I in the milk was developed as a result of the accident. The amount of ^{131}I in the milk will "exceed 0.1 μCi/l if it is produced by cows grazing in an area where the gamma levels exceed 0.05 mR/hr."

The Los Alamos Scientific Laboratory Criticality Accident, December 30, 1958

This criticality accident occurred during an inventory at a plutonium extraction and purification plant. The plant's primary mission was to recover plutonium residues from machinery. In the ordinary operation of the plant, most of the plutonium was extracted by chemical means, giving concentrations of several grams per liter of solvent. Small amounts of the plutonium normally remained behind in the extraction equipment, which was periodically separated and collected. Ordinarily, high-level material was stored and handled separately from that obtained when the tanks were cleaned.

Inadvertently, highly concentrated plutonium was added to a tank containing low level material (Figure 4). As a result of this error the tank contained:

1. 87.4 gallons of aqueous solution with 40 gm of Pu.
2. 42.2 gallons of solvent (in one layer) with 3.27 kg of Pu.
3. Solids containing 60 gm of Pu.

The material in the solvent layer, which was immiscible with the water layer, was barely subcritical before the inventory operation started.

The chemical operator started a stirrer in the tank which resulted in achieving criticality (Figure 5). Effectively, the stirrer caused one-half inch decrease in the radius of the solvent layer, thereby concentrating the plutonium which formed a critical mass. Later analysis showed that the number of fissions which occurred was in the neighborhood of 1.5×10^{17}. Neutron induced gamma radiation levels in the room following the fissioning were as follows:

Date	Time	Radiation Level
12-30-58	4:40 pm	20 R/hr at 25 feet
	9:45 pm	0.1 R/hr at 25 feet
01-01-59	9:00 am	2 R/hr at contact

When the solution went critical, there was a blue flash, a report, and the operator fell off his stand. The tank was moved 3/8 inch but was not ruptured and no contamination was spread. After the excursion, the operator apparently turned the stirrer off and then on again.

Two other operators who were in the same building went to the man's aid, one of them passing very close to the tank. Suspecting an acid burn, th led the injured man to a shower, the second operator turned off the stir as he passed the tank for the second time.

The highly exposed operator went into deep shock shortly after exposure, but regained consciousness about six hours later. He died at 3:15 a.m. on January 1, 1959.

Doses to the operators have been estimated at 12,000 rem $\pm$ 50 percent, 13 rem and 53 rem, respectively.

A number of lessons were learned as a result of this accident:

1. Reliance on operational procedures is not always safe; the possibili of human error must never be overlooked.

2. Radiation alarm and emergency procedures were inadequate. (Two opera tors thought that the accident involved an electrical short or chemic explosion and they did not know that high radiation intensities exist in the room.)

3. The design of all atomic processing installations should include consi deration of all parameters in the equipment including critically safe geometries for process vessels and alarms.

The Oak Ridge Plutonium Release, November 1959

In November, 1959, a chemical explosion occurred in a plant used for chemic processing of highly irradiated reactor fuel. The explosion was evidently the result of insufficient flushing of an evaporator after decontamination.

The acid residues in the tank reacted violently when hot nitric acid was added.

The explosion blew out a door spreading plutonium contamination to the street and surrounding buildings. Not only was the individual cell in the processing area contaminated, but also the plutonium was forced through wiring conduits into the remainder of the building. Airborne contamination outside the building was then pulled into the ventilating system of a nearby reactor.

Activity released in the explosion ran as high as 10^8 dpm/100cm^2 in the cell involved, to an average of 100 dpm/100cm^2 in the street. A penthouse above the cell was contaminated to 50,000 cpm/100cm^2, and some streets and buildings in the vicinity ran as high as 100,000 cpm/100cm^2 (Figure 6.) Under these conditions, it is a tribute to the accident control personnel that no one received more than the maximum permissible body burden.

A procedure for decontamination was set up, starting at the less highly contaminated areas and moving up to higher levels. Initially, much of the plutonium was fixed in place by resurfacing roads and spray painting buildings, equipment, and even grass. A number of procedures were employed for the final decontamination which included vacuum cleaning, abrasion, and acid. Over eight months were needed to completely "clean up" the area. It is significant to note that only about 15 grams of plutonium were blown off the evaporator cell and this relatively small amount of material resulted in an expense of over $100,000.00, and an eight-month shutdown of an important research facility. The lesson learned from this accident was that a small amount of radioactive material can cause a severe and costly contamination problem.

Shipping Incident, November 20, 1960

This particular incident is an excellent example of the degree to which poor judgment can affect routine operations and personnel safety.

A truck was transporting a 19-ton shipping cask containing irradiated fuel elements (Figure 7). The planned route required that several state lines be crossed. At one of these ports of entry the truck was not allowed to pass because the weight on the rear axle exceeded that allowed by state law. The driver and courier arrived at the expedient of moving the 19-ton cask forward by loosening the tie lines slightly, then accelerating the truck up to a few miles per hour and suddenly applying the brakes. The method worked; the weight shifted and the truck was allowed to proceed.

Later, at a large town, it was again decided to shift the cask forward to meet another state's requirements. This time the load would not shift on a level road so the truck was taken to a hill and the brakes were applied at a speed of 15 to 18 miles per hour. As a result, the one-half inch tie-down pins failed and the cask rapidly slid forward 15 feet (Figure 8).

It collided with the sleeper compartment and injured the foot of the courier who was in the compartment.

The immediate radiation survey showed no activity leakage. However, at the next terminal the load was shifted to a new trailer and immediately began to leak, contaminating the trailer bed to 250 mR/hr. The cask was then transferred to a third trailer which was also found to be contaminated at its destination.

The lesson to be learned from this incident is obvious. Unfortunately, no

matter how competent or well-trained people are, the old axiom "familiarity breeds contempt" seems to apply on many occasions. While this problem can never be completely eliminated, it can at least be minimized by proper orientation of personnel. The basic cause of this incident was poor prior planning.

The SL-1 Reactor Incident, January 3, 1961

The SL-1 was an experimental boiling water, low power nuclear reactor. It had been shut down on December 23, 1960, after approximately two years operation. Routine maintenance was scheduled and the SL-1 was to resume operation on January 4, 1961.

On the night of the accident, January 3, 1961, three military personnel were on duty at the reactor. A security guard at a neighboring area noted the portal radiation monitor near him had alarmed. No one was present, so he reset the alarm which rang again. He telephoned the instrument repair section and reported a malfunctioning monitor.

The first indication that anything had gone amiss was activation of a heat detection alarm which sounded at the fire station. The fire department and security units reported to SL-1. The assistant fire chief entered the building, read radiation intensities on the order of 25 R/hr, and retreated from the building after searching the lower levels for the three men. Fifteen minutes later, two more firemen and a health physicist reentered the building, read radiation intensities of about 500 R/hr (available instruments read only 500 R/hr full scale and were "pegged"), and evacuated the building. Fifty minutes later, after it had been positively determined that the three operators had not left the area, two more personnel entered the operating

level and found two of the operators, one of whom was still alive retreated and obtained help. The one operator who was alive was but died shortly thereafter from head injuries. The second body moved the evening of January 4th. The third man was eventually d pinned to the ceiling by a control rod cover. The last body was several days after the accident (the morning of January 9th).

Radiation levels in the SL-1 building were in the range of 1000 R/ The bodies of the operators read 100 to 500 R/hr at six inches. the first time that human bodies were, in themselves, hazardous sc an entirely new phenomenon. High radiation levels made it impossi immediately disassemble the core to prevent further excursions and determine the cause of the accident. It is estimated that the cor tained one million curies of long-lived fission products. The cor pressure vessel of the reactor were not removed to hot cells for d tling until eleven months after the accident (Figure 9).

Of more than 200 people involved in the incident, only 22 received in excess of the permissible maximum. The maximum gamma dose was 2 and the maximum whole-body beta dose was 120 rem. The monetary los the excursion was $4,350,000.

While it has not been determined what the actual cause of the excur was, it seems probable that it was a result of the excessive withdr of the main control rod while one of the operators was attemping to nect it to the drive mechanism.

One lesson learned from the SL-1 accident was that, while the buildi was not designed to contain released material, it allowed only a rel

small amount of active material to escape (about 10 Ci ^{131}I) and external environmental contamination was slight. Other lessons learned from this incident showed that very high-level beta-gamma instruments are needed on all teams. Their range should be on the order of 10,000 R/hr.

The possible need for decontamination facilities for a large number of persons and the need for medical facilities for a large number of contaminated and injured personnel was brought out as a result of this accident. Also, the need for protecting team personnel from overexposure in initial efforts to preserve their usefulness in later operations was demonstrated during recovery operation.

Weapons Accidents

With the advent of the nuclear weapon, a new dimension was added to the concern for public safety. Weapons must be continually moved about, renovated, and taken in and out of stockpile. In view of this, it is not surprising that a few accidents have occurred. Most of the accidents that have occurred have been "minor". Rather than covering a large number of accidents, a review of several more pertinent occurrences will be discussed.

When nuclear weapons first entered stockpile, they were shrouded by heavy security. This kept personnel such as guards and firefighters at a stockpile base "in the dark" as to the presence of weapons in the vicinity. This tight security undoubtedly served some purpose. At the same time, however, it effectively decreased the efficiency of accident control personnel as demonstrated by the following accident:

An aircraft crashed on a military base in the United States. Although th plane carried weapons, emergency personnel were unaware of the fact and fought the fire as if it were an ordinary accident. The crash site was i the center of a populated area and a large crowd of spectators gathered. Unaware that a weapon was in the plane, these people were much too close to the wreckage. As the fire was being fought, the high explosives detonated, killing a number of bystanders, including the commanding general of the base.

As a result of this disaster, security measures were changed to the extent that emergency personnel are informed when nuclear weapons are present. Also, better training was instituted in weapon fire fighting and emergency team operation.

During the early 1950's most emergency radiological teams were very poorly equipped and organized, where they existed at all. This state of affairs eventually reached its culmination in another accident at a military base.

A jet bomber carrying a nuclear weapon crashed on a runway when its landing gear collapsed. The plane began to burn immediately and the fire was allowed to burn itself out. Erroneously, a full nuclear contribution was anticipated and the entire base was evacuated. Aside from the fact that evacuation was unnecessary, it alarmed the surrounding civilian populace.

After the fire went out, the area was monitored with a gamma survey instrument and no contamination was found. With no further precautions, the wreckage was pushed off to the side of the runway. It is important to note at this point that the only alpha monitoring instrument on the base was

backed over by a vehicle upon arrival at the scene, resulting in a complete loss of alpha monitoring capability. The weapon components and debris were recovered, crated, and transported to the USA on a transport aircraft. Several days later the wreckage was monitored by an emergency team called in to assist at the accident scene and was found to be highly contaminated with plutonium. Subsequently, this contamination was found to have spread not only throughout the base involved, but to a naval base some 40 miles away and even to various locations across the country.

A large number of vehicles and aircraft were found to be contaminated. Fortunately, only one individual received a significant dose - some two-and-one-half times the maximum permissible body burden for plutonium-239.

Significant to this particular accident was the limited amount of equipment available to emergency teams at that time.

Lessons learned from this incident include the following:

1. Good public relations are necessary and must be maintained to avert public alarm.

2. Local authorities must know what to expect from a weapon that is involved in an accident.

3. Accident response teams must be well organized and equipped.

4. A central coordinating unit is needed to provide and coordinate outside help when it is needed. The Joint Agreement of 1958 and the Joint Nuclear Accident Coordinating Center came into being as a result of this accident.

We still continue to learn from each individual accident. As an example, a plane carrying three thermonuclear weapons crashed just off the end of a runway at a southern base. In most respects, this accident was very well handled. Contamination was not allowed to spread; press and public relations were excellent. The only point open to question is that the fire was fought with foam. This procedure appeared to be effective since the layer of foam seemed to extinguish the blaze. However, it began to rain. The foam was washed off, and dormant fire re-ignited. When agents other than foam are available for fire fighting they should be used, particulary if the weapon is at a high temperature (300° F.) or is actually burning.

On January 16, 1966, an aerial refueling accident, involving a B-52 bomber carrying four nuclear weapons containing Pu, occurred near a Spanish village. Two of the weapons were recovered intact, but the high explosive component of the other two devices detonated, dispersing Pu over a restricted area. The cloud from one weapon spread across an irrigated agricultural area containing tomatoes and alfalfa ready for harvest. The other cloud drifted across more agricultural land and through the northern third of the village.

Following the establishment of contamination contours, negotiations were initiated with regard to cleanup of the affected areas, although there were no realistic or official standards for determining a course of action. In final agreement, all crops were removed from the field and destroyed where readings for ^{239}Pu were above 5 mg/m^2 (35 pCi/cm^2). All areas between 5 and 500 mg/m^2 (3500 pCi/cm^2) were plowed to a depth of at least 10 inches to decrease the possibility of resuspension of the Pu-oxide particles.

Subsequent to the plowing program, it was discovered that the agricultural land was on a delicately balanced salinity situation. Rainfall and irrigation had been sufficient to keep the excess of soluble salts in the lower part of the profile, but the plowing brought the excess soluble salts to the soil surface, with adverse effects upon crop production. This illustrates one of the environmental dangers which may be encountered in any type of decontamination operation. The cure may be worse than the original disorder; therefore, such problems should be ascertained before corrective action is taken.

On January 21, 1968, a B-52 bomber carrying four nuclear weapons crashed on the ice near Thule Air Force Base in Greenland. The chemical explosive devices on each of the bombs were detonated so that over 3100 grams of ^{239}Pu was spread over an area of 2.23×10^5 m^2. The Pu oxide dust was either deposited to shallow depths in the ice (usually less than one centimeter, but up to 10 centimeters where the burning jet fuel had melted the snow which had refrozen with the Pu embedded therein) or was present on the aircraft wreckage. Also associated with the accident was 120 curies of tritium which was judged as not constituting a hazard as it was concentrated with the high-level Pu contamination - most of it would be removed with the Pu contamited materials.

The smoke cloud from the burning aircraft carried finer particles some 11 miles toward inhabited areas, but deposition levels were far below danger levels.

A total of sixty-seven 25,000-gallon tanks were used in the cleanup of contaminated material which resulted in shipping 600 containers of

contaminated material to the USA for disposal. The cleanup area extended out to the 3000 pCi/cm^2 level of ^{239}Pu which required the removal of 70,000 m^2 of surface area 10 cm deep. This removed approximately 99 percent of the contamination. To essentially remove 100 percent of the contamination would have more than tripled the amount of surface material which was removed.

Only aircraft accidents have been covered here, not because they are the most common (vehicle accidents are more frequent), but because they are usually the most serious as far as hazard control is concerned. All emergency radiation team members must be cognizant of the fact that many varibles exist in association with a weapons accident. Hence, much study and keeping "up to date" is required. One way of bettering ourselves is through reviewing past incidents while preparing for those to come.

This chapter has covered a number of radiological accidents. While these are not all that have taken place, they do give an overall view of the type of incidents that can happen. In the past, we have been fortunate that most incidents have not presented a hazard to a large segment of the population. It is obvious that in any accident involving many people, the control and publicity problems will be tremendous.

It is disquieting to note that the majority of the accidents have resulted from either human error or poor judgment. As mentioned, the frequency of this type of accident can be greatly reduced, but can never be completely eliminated.

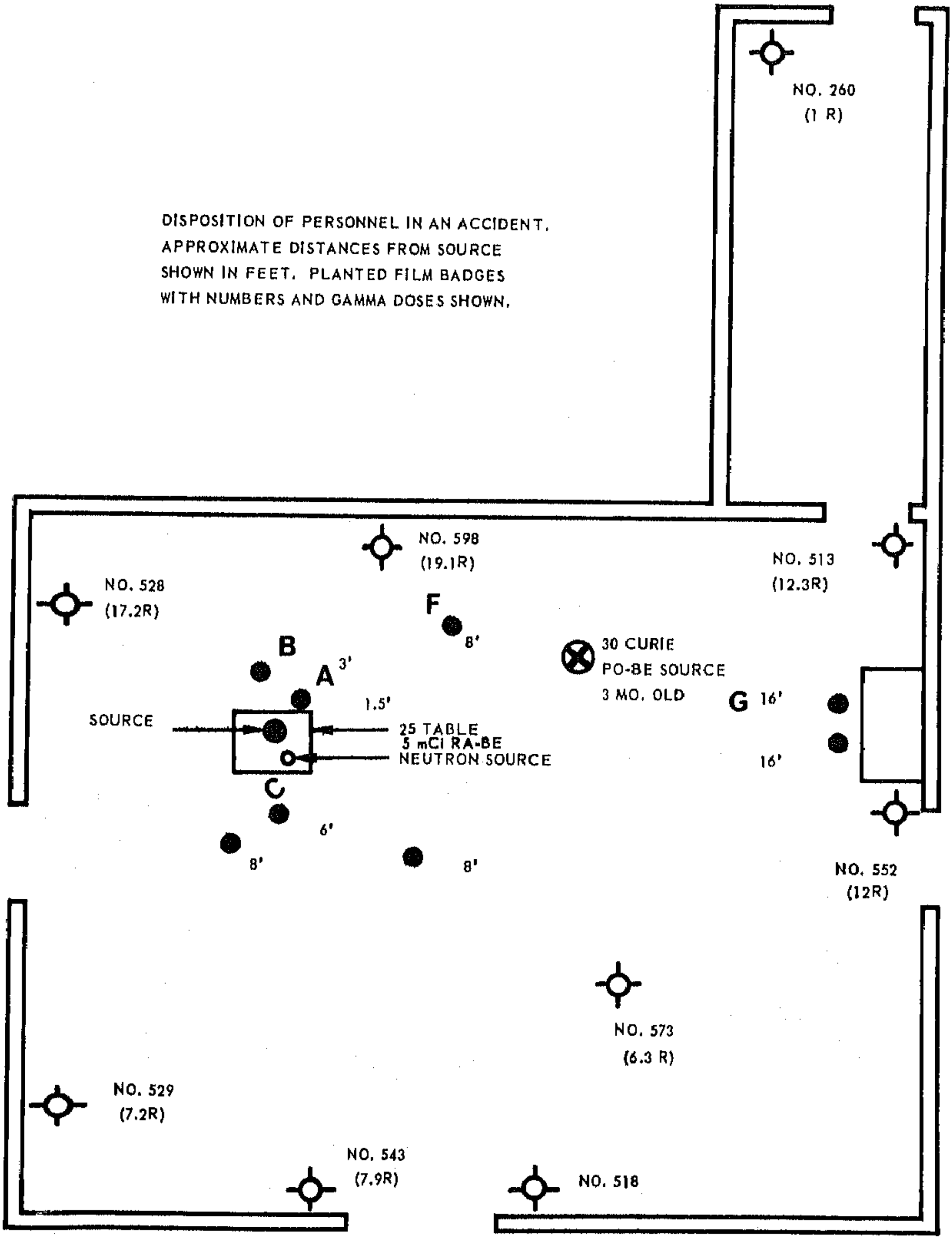

Figure 1 Disposition of Personnel

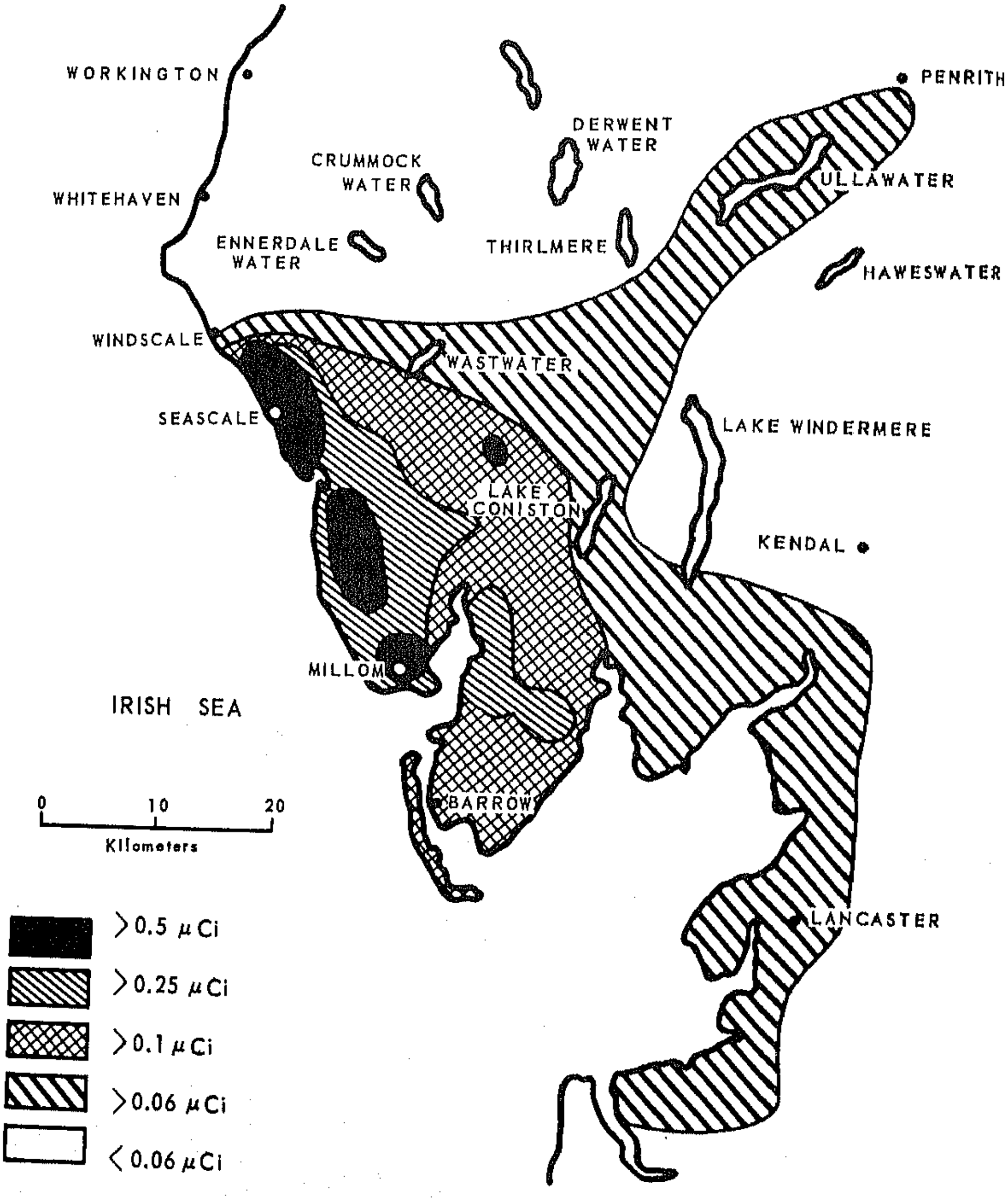

Figure 2 Windscale Contamination

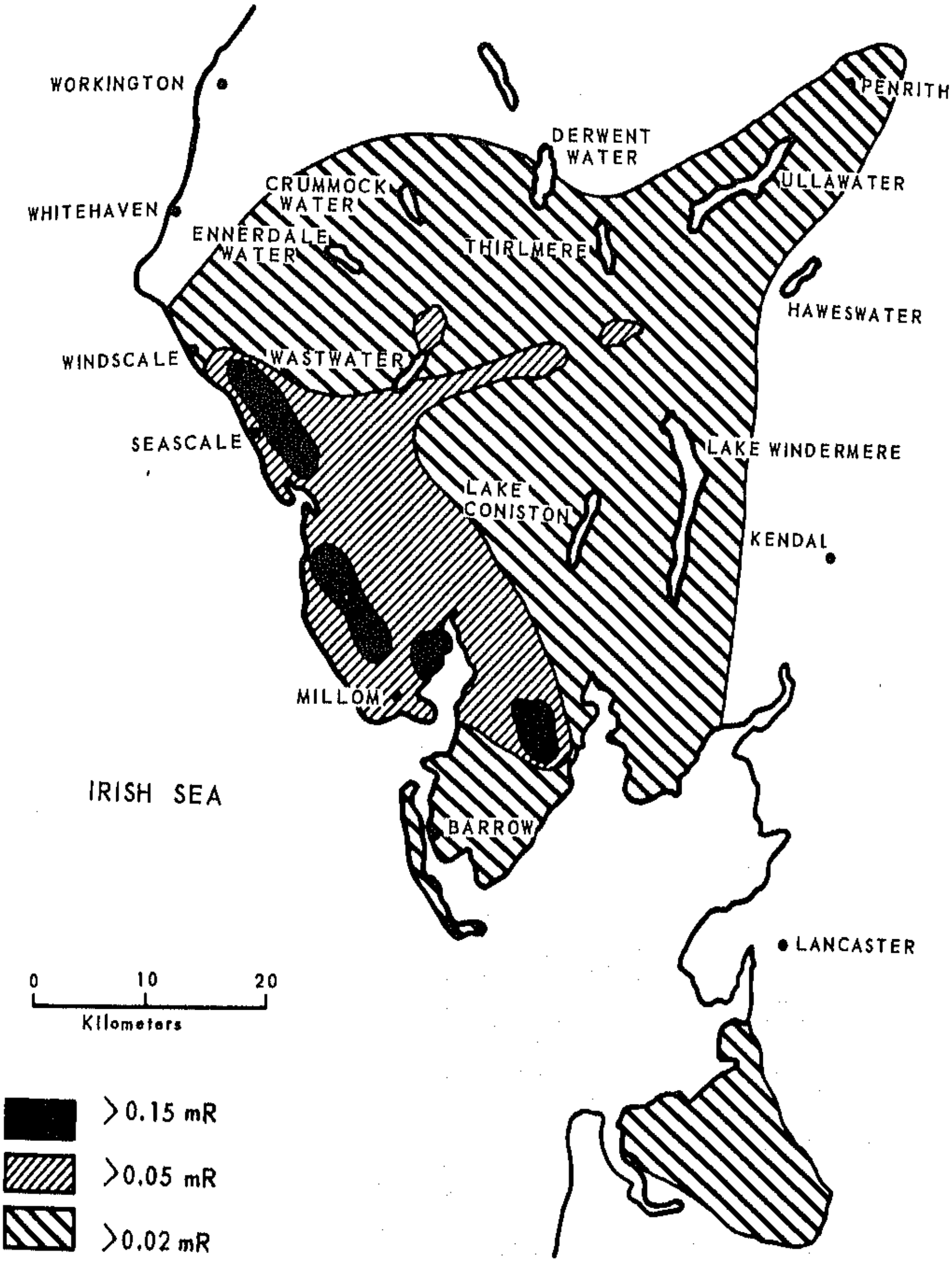

Figure 3 Windscale Contamination

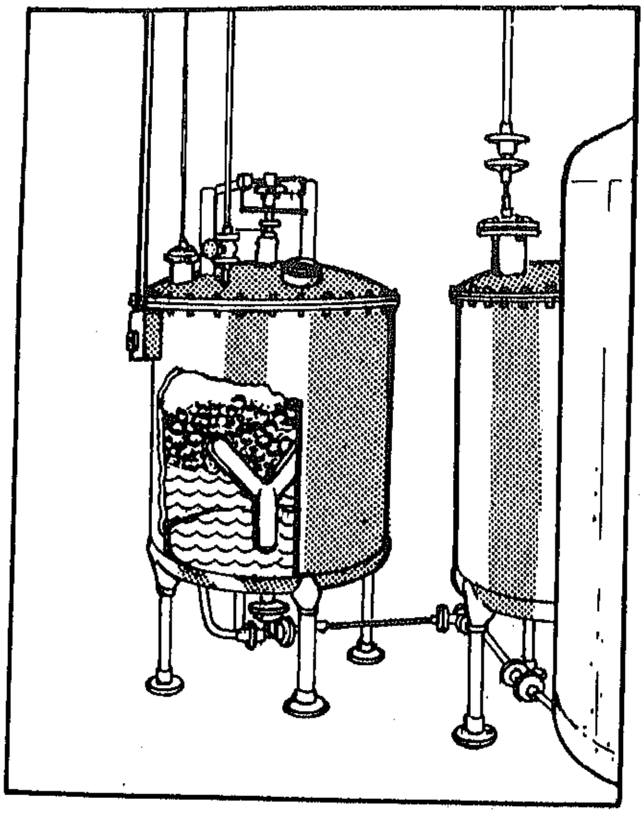

Figure 4 Tank Containing Plutonium

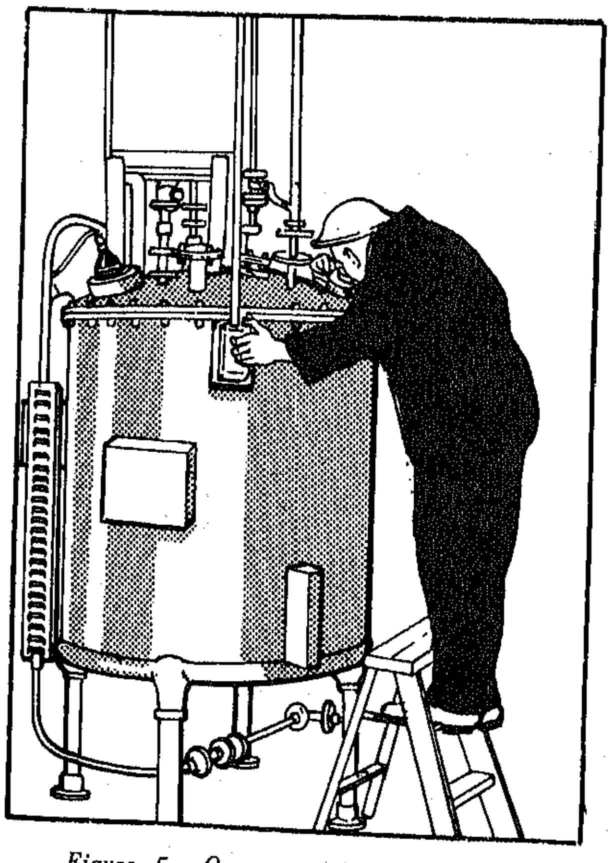

Figure 5 Operator at Time of Accident

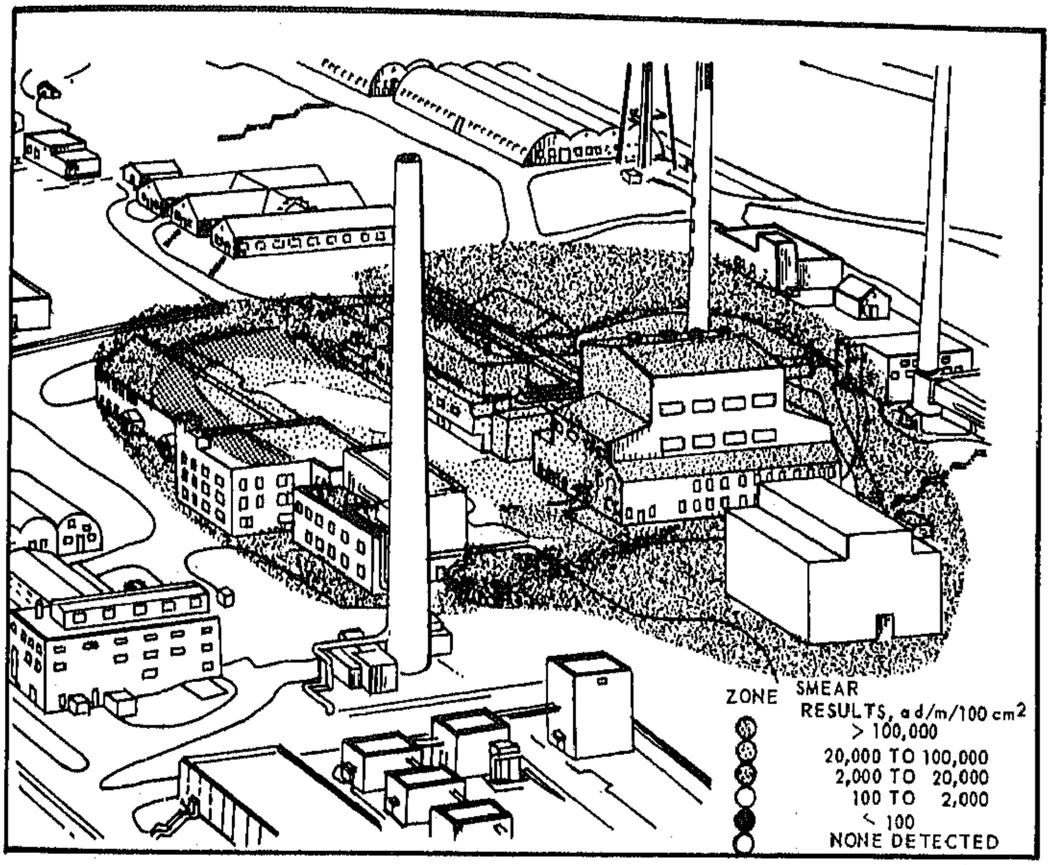

Figure 6 Oak Ridge Plutonium Contamination

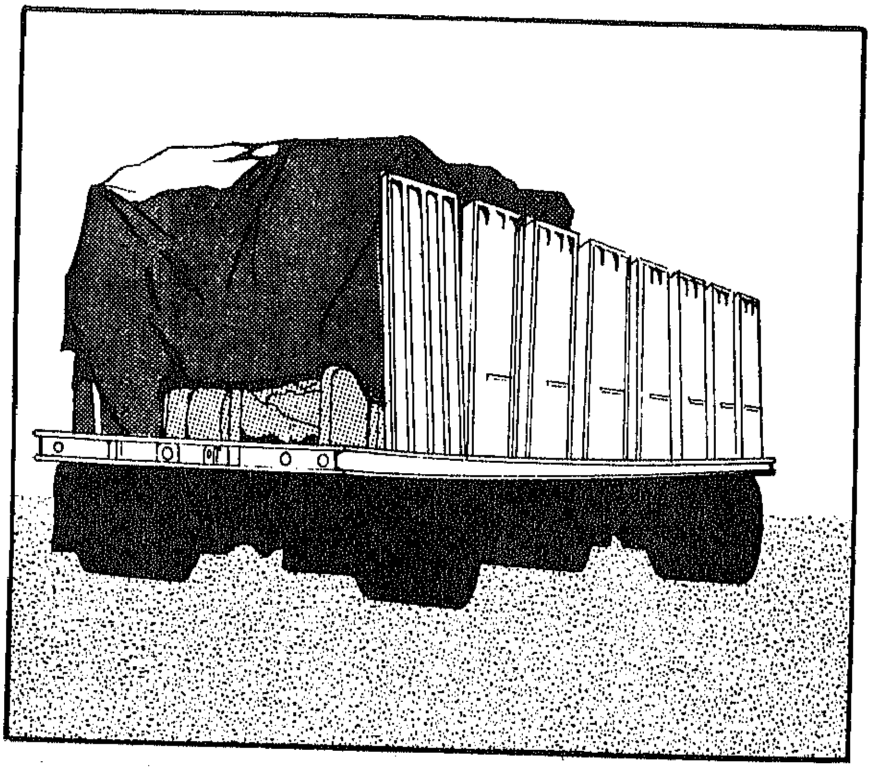

Figure 7 Truck Transporting Shipping Cask

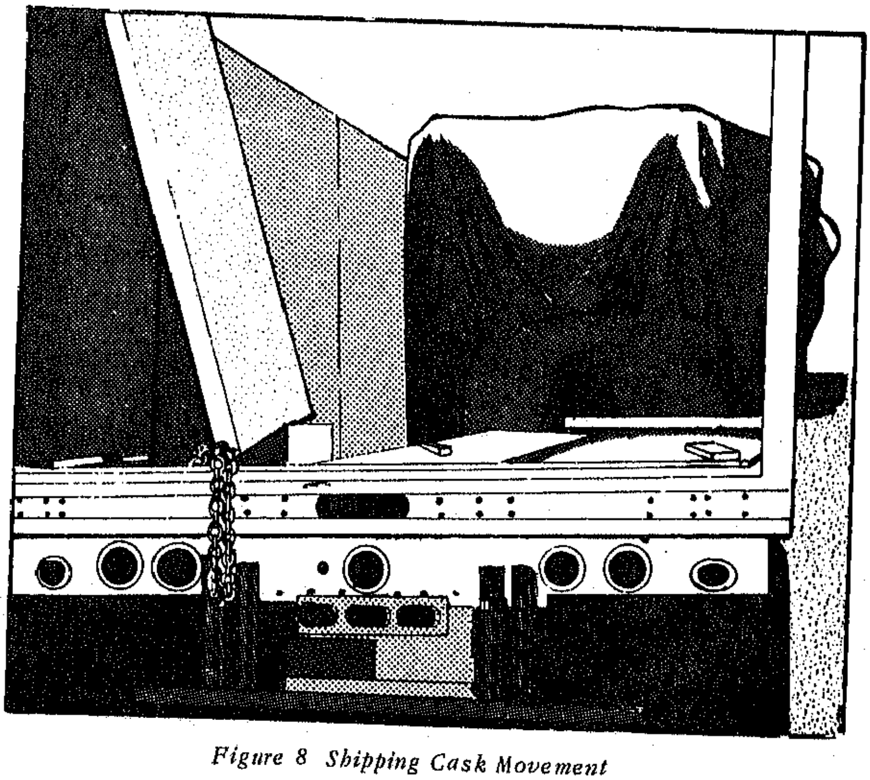

Figure 8 Shipping Cask Movement

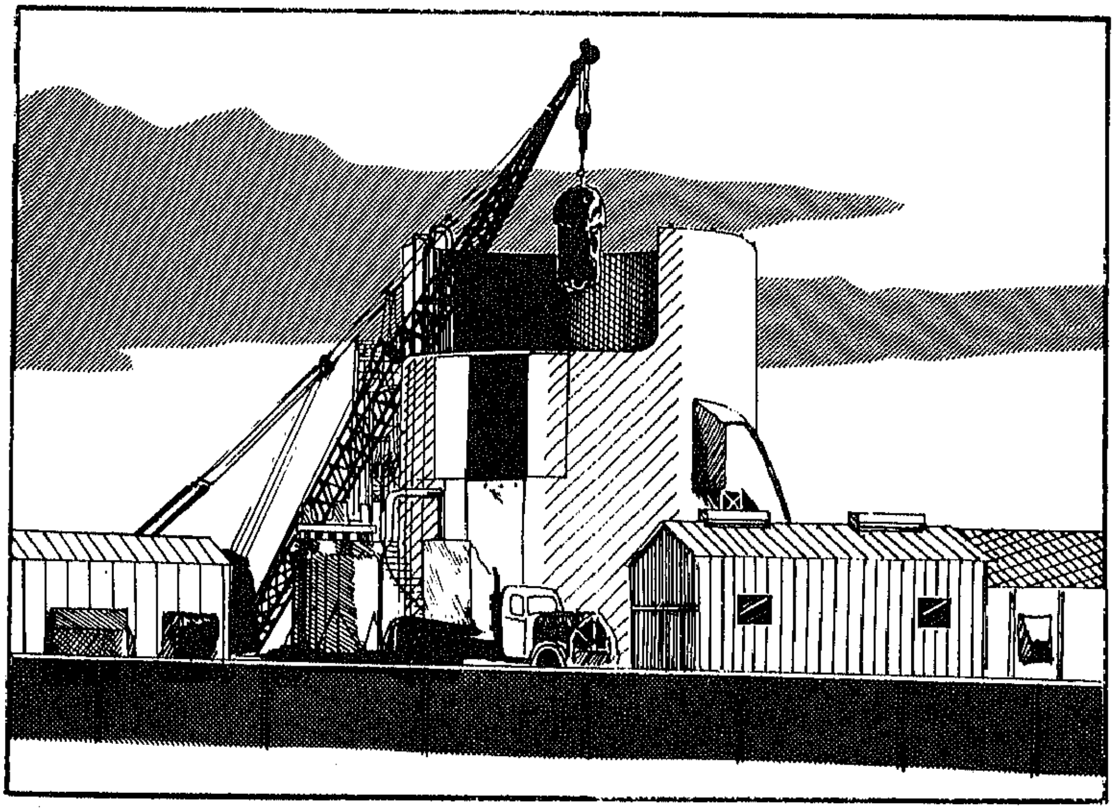

Figure 9 SL-1 Core Removal

SECTION 26

EMERGENCY TEAM OPERATING PROCEDURES

In order to maintain optimum capability and mobility, membership in a radiological emergency team must be limited to persons with extensive training. The team must be able to function calmly and efficiently under a variety of adverse conditions.

Many organizations have the capability to deal effectively with conventional accidents. The radiological emergency team is trained to supplement these existing capabilities. It is doubtful that a team would be called upon unless nuclear materials were involved or suspected of being involved in an accident.

When the radiological emergency team is the first group to arrive at an accident scene, it may be forced to deal with a number of health and safety problems. Table 1 represents a checklist of personnel which might be required in dealing with an emergency. Other groups possessing varying capabilities will be responsible for rendering first aid, fighting fire, and controlling persons in the area. Most civil groups do not have the capabilities to deal with high explosives or radiological problems.

If the accident involves a nuclear weapon or classified materials, security considerations must be recognized. Every effort should be made to prevent the compromise of classified information or material. Weapon components should be concealed from spectators until they can be properly removed by persons authorized to do so.

When possible, a member of the team should be designated as a "technical

reporter." This person should record every event, radiation exposure, and other data starting with the team alert and continuing until the team returns to its base. This log will be the team's official record of damage and assistance. It will be necessary for use in subsequent evaluations of the accident by persons not at the accident. Since it may also be considered a legal document, all entries must be carefully worded and accurately documented.

Before the team can take remedial steps, hazards must be located and evaluated. The process of detecting and evaluating the hazards associated with an accident begins when the team is notified of the accident. Early information may be second hand, but should not be disregarded. The person reporting the accident, the organization summoning the team, and any witness can all furnish some information. This information may have greater reliability with respect to conventional hazards than to radiological problems but should nevertheless be obtained and recorded.

Much radiological information may be gained indirectly while the team is engaged in other tasks. Radiation detection instruments should be turned on and checked before the team reaches the scene. They should also be carried while the area is being cleared and demarcated.

If instructions can be transmitted to on-the-scene personnel and are carried out while the team is enroute, the area may be ready for immediate evaluation of radiological hazards upon arrival. If not, the team must be prepared to advise fire-fighting, medical, and law enforcement groups in regard to radiation hazards as they perform their various emergency functions. At the scene, the team captain should seek out the person in charge

and make the services of the team available to him. This individual may be a civil authority, a military commander, the representative of the owner responsible for the materials, or the official in charge of the facilities or operations that are involved in the incident.

If casualties and spectators have not been cleared from the area, this should be done by local law enforcement personnel. The team should demarcate an exclusion area and request the services of the civil authorities in preventing unauthorized entry. All personnel who may have been exposed to contamination should be located and monitored. Bioassay samples should be taken when necessary. Information such as names, addresses, telephone numbers, occupations, degree of injury, and contamination information should be recorded.

A contamination control point (hot line) should be established on the perimeter of the serious hazard or danger zone, but within the exclusion area. By so doing, the team will minimize congestion at the hot line. All entries to and exits from the danger zone should be made through the hot line. Two team members should be designated hot line monitors and given the responsibility to properly equip personnel entering the area and to monitor all exiting personnel leaving the danger zone.

All entry parties should be equipped with anti-contamination clothing, respiratory protection, and personnel dosimetric devices until the absence of radiation in the area is verified.

Ideally, the hot line should be situated upwind and uphill from the scene of the accident. It should be in line with the route of easiest access to

the accident area and should occupy sufficient area for entry and exit parties to be processed without confusion. Anti-contamination clothing and equipment are issued at this point and containers are arranged there to serve as receptacles for contaminated clothing and equipment. When possible, butcher paper or roofing paper should be spread along side the receptacles to provide an easily renewable walkway. When the paper becomes contaminated, it can be rolled from the clean side to the contaminated side and stored for removal as contaminated waste. Polyethylene bags are conveniently stored and transported for use as waste receptacles.

The hot line serves two basic functions. It is the control point for preventing the removal and spread of contamination, and it is the field station for controlling access and exposure.

All personnel desiring access should have the permission of the team captain. With this permission, they may be issued anti-contamination clothing and equipment by hot line monitors. Their names, organization, address, previous exposure, dosimeter number, and time of entry are noted. When they exit, they are monitored and logged out of the area. Time of exit and dosimeter reading are noted and exposures totaled.

Areas should be set aside near the hot line for personnel and vehicle decontamination. Also, a clean area should be established for collection and storing bioassay samples.

Somewhere on the exclusion area perimeter, a field headquarters or forward control point (FCP) should be established. The FCP serves as a nerve center for the entire area and as a buffer between spectators and the hot line.

The FCP should have direct communication with the team's home base or the nearest DOE office as well as civil authorities in the vicinity of the accident. If necessary, communications may be maintained through the equipment and systems operated by state of federal agencies. All information made public concerning the accident should come from the FCP and should be released by the officials of the organization responsible for the material or operations involved in the accident.

While the primary responsibility of the emergency team is dealing with radiological hazards, the situation with regard to explosion, fire, and chemical toxicity hazards may require immediate steps to be taken upon arrival at the accident scene.

The first deliberate attempt by the team to gather information should take the form of a scouting party. The scouting party is briefed by the team captain prior to entry into the problem area. Exposure limits, length of stay-in time, and what might be encountered are discussed. Upon return and after clearing through the hot line, they report to the team captain for debriefing. This team will consist of at least two men well trained in hazard detection work and fully equipped for the worst contingencies which might exist in the area. Their mission is to make a brief visual and instrument reconnaissance of the immediate area and return promptly with information.

This party should be on the alert for immediate or chronic hazards which exist in the area. These may consist of mechanical hazards from debris, spilled gasoline, acid or solvents, downed electrical wires, and explosives. In confined space, the most acute hazard may be chemical toxicity. Radiological information to be gathered would include the type of radiation,

general intensities, and the nature of the radiation source. In addition, the scouting party should note any other information which would assist the team captain in deciding how to bring the hazards under control. The nature of the terrain, the disposition of debris, and possible survey routes should also be noted.

When the most serious hazards have been eliminated or stabilized in the area and the scouting party has returned, a detailed radiological survey is made to accurately measure the extent and intensity of contamination. This aspect is discussed in other chapters of this manual.

Another method of gathering valuable radiological information is air sampling. The principal method of incurring internal radiation exposure is the inhalation of radioactive material. Air sampling should be done downwind from the accident as soon as possible after the team's arrival. Preliminary checks for airborne contaminants may be made by surveying swipes taken from the nostrils of personnel who have been exposed, monitoring clothing or vehicles from within the area, and by monitoring the respirator filters worn in the area by firemen or other emergency personnel.

The four most frequently encountered personnel hazards associated with accidents involving nuclear materials are fire, explosion, toxicity, and radiation. Radiological emergency team members must be conversant with hazards other than radiation since the team may be asked to advise or assist other groups dealing with these hazards.

Fire Hazards

The wide use of combustibles ranging from fuels and solvents to pyprophoric metals enhances the possibility of fire. Fire poses special problems when radioactive materials are present, even though fire will neither accelerate nor retard the emission of nuclear radiation. Fire will, in many cases, alter the chemical or physical form of the radioactive material and contribute to its dispersal. Information relative to weather conditions and downwind monitoring information should be recorded for later reference.

If fire has broken out at an accident scene, every effort should be made to remove radioactive material to a safe distance from the fire. If the fire has reached radioactive material, no attempt should be made to fight it unless public protection dictates that this be done. Casualties and spectators should be removed to a safe distance (at least 1,500 feet) from the accident. Should it prove necessary to enter the smoke to save a life, every precaution should be taken to reduce eye and throat exposure and an expeditious means of evacuation should be planned. Brief exposures in such cases may be tolerated, but longer exposures (e.g., to fight the fire) will warrant the use of adequate respiratory equipment. Approach to the fire from upwind and uphill with self-contained breathing apparatus is recommended. All personnel exposed to the smoke must be monitored.

If the accident involves a nuclear weapon, the same general procedures should be used. If the weapon is not engulfed in flames, its temperature should be kept below 300° F. If it is engulfed in flames or is ruptured, the detonation of its high explosives is probable and the area must be evacuated immediately.

Additional fire hazards exist with certain radioactive or fissionable materials. Plutonium, uranium, and thorium may exhibit pyrophoricity. Plutonium-239 and uranium-235 are capable of supporting a nuclear chain reaction. If sufficient quantities are immersed in water, the chances for criticality are enhanced.

Some powdered metals will burn. Among these are copper, brass, bronze, iron, stainless steel, nickel, zinc, cobalt, aluminum, magnesium, zirconium, and titanium. Sodium will also burn, generating sodium oxide which may combine with moisture to form sodium hydroxide. Commercial metal fire suppressants should be used on all metal fires as water may cause violent reactions.

Explosive Hazards

Explosive hazards exist to some degree wherever there is a fire and may also be present in the absence of fire. Nuclear weapons contain high explosives (HE) which may be detonated by fire or impact. If the weapon is broken and the HE is exposed to sunlight or extremes of temperature, its sensitivity to shock or impact may be greatly increased. If the HE detonates after personnel have been evacuated from the vicinity, the principal problem will be the scattering of nuclear material by the explosion and unexploded HE. To date there have been no cases of apparent nuclear contribution associated with accidents involving nuclear weapons.

Many solvents and fuels generate explosive vapors. A number of gases used in DOE work may be explosive as are the fumes from burning paraffin.

No detailed procedures can include all of the possibilities associated with explosive hazards. General safety procedures would include personnel evacuation and explosive mixture surveys with an explosimeter.

Toxic Hazards

Toxic hazards are difficult to anticipate. The emergency team will usually await the abatement of these hazards before dealing with radiological hazards. Toxicity may result from a variety of sources. Some materials used in atomic energy work are toxic in the form in which they are used, such as plutonium and beryllium. Others may form toxic materials when they are burned. The HE used in nuclear weapons gives off toxic fumes while burning as do some solvents and many metals. Any fire in an enclosed space may contribute sufficient carbon monoxide or carbon dioxide for the atmosphere to become toxic. Before entry is made into such a confined space, tests with a toxic material detector should be made as well as with an oxygen content device to indicate any oxygen deficiency in the air. Self-contained or supplied air respiratory equipment should be used for all entries in closed spaces.

Radiological Hazards

As has been mentioned, three of the major types of hazards (fire, explosion, and toxicity) are essentially the responsibility of groups other than the radiological emergency team. Radiological hazards may be associated with naturally occurring radioactive materials, fissionable elements, or materials made artificially radioactive by neutron activation.

From the time of the alert, the emergency team will be attempting to accurately determine and evaluate the radiological situation at an accident. As stated, the team will gather second-hand information from witnesses, incidental information gathered while accomplishing other tasks, and preliminary technical information deliberately gathered by a scouting party. When all of the information has been considered, the team prepares for detailed radiological surveys.

The team captain must determine a number of procedures to be used by the team for these surveys. The team must also be briefed concerning the extent and type of anti-contamination protection to be used, length of time to be spent in the area, and the survey methods to be used.

The radiological survey team should consist of at least two men. Their duties will be to make radiation measurements, referencing these to known locations and recording them. Since the information gathered by a survey team must be plotted for analysis, a consistent method of recording measurements should be used. This could include survey forms for recording the following information:

> Reference point, direction from reference, distance from reference, distance of detector from emitter, intensity, and time of measurement.

Additional blanks should be provided for area, date, assignment, survey meters used, sampling data, monitor's signature, estimated dose, and maximum measurement obtained.

Usually, an eight-point radial survey is initially conducted, depending on the specific situation. If radiation intensities are high, several teams can split the survey. At an accident scene, the area to be surveyed may be relatively small, allowing a two-man team to survey all eight radials. In the absence of roads or other established reference points, azimuths and distance from the accident may be used.

If large scale maps of the area are available, they can be used for plotting and briefing purposes. If they are not available, maps may be drawn on any rectangular coordinate paper. The plotting of isodose lines will be useful in obtaining an overall "picture" of the radiological situation.

Any monitoring team should pay particular attention to radioactive "hot spots." These may exist inside or outside of a low radiation intensity field. If an explosion has occurred, the likelihood of "hot spots" is increased. The location of these, as well as other measurements, should be carefully documented and, where possible, marked on the ground. This will enable multiple measurements to be made at the exact same location for radioactive decay studies and subsequent decontamination.

Alpha surveying requires meticulous care, and the alpha detectors must be brought within one-quarter inch of the area monitored to insure optimum results. Usually the monitor wears gloves and holds the probe in such a fashion that the fingers slightly extend beyond the probe. The fingertips are then brought into contact with the surface and the probe remains slightly raised. This serves two purposes: it prevents probe contamination and serves to protect the thin "skin" on the probe from punctures.

The probe of the alpha detector should be held in place for at least 30 seconds to assure accurate measurements. In addition, several measurements are taken and averaged to produce one reportable measurement. Alpha cannot be monitored if the surface is wet with water or oil. If plutonium is the contaminant, a PG-1 probe will detect its presence by gamma emission even though water or oil are present, but the measurements will not be quantitative.

Air sampling should be accomplished if any trace of contamination is detected. If marginal concentrations are detected or indicated on air samples, it may be deemed necessary to determine the naturally occurring radon-thoron background in the area.

Airborne contaminants may be reduced, if they result from resuspension, by using water or oil as a fixative agent. In such cases, care should be taken to prevent run-off of contaminated liquid.

Decontamination will not normally be a team responsibility. However, the team may be requested to advise personnel conducting the decontamination work as to the necessary steps required to restore areas, facilities, and equipment to normal service.

In the absence of officially established radiation protection and contamination release guides and/or the lack of positive identification of the contaminant, items 1 through 6 listed in Table 2 can be memorized and represent reasonable limits for the release of contaminated or radioactive personnel, equipment, or materials. Item 7 represents the air concentrations of gross radioactivity above which respiratory protection should be required for team personnel. These values are for use in the worst possible case. Where feasible, the values listed in ERDA Manual Chapter 0524 or 10 CFR 20 should be followed.

Table 1

Radiolgoical Emergency Team Personnel*

PERSONNEL	TRAINING
Team Captain	Trained in health physics and administration.
Technical Recorder	Trained in health physics and documentation. Acts as assistant team captain.
Radiation Monitor	Trained in all aspects of radiation monitoring.
Electronic Technician	Trained in repair and maintenance of portable radiation detection instrumentation.
Nuclear Weapons Specialist	Trained in design, assembly, checkout, and maintenance of nuclear devices.
Nuclear Weapons Disposal Specialist	Trained in explosive ordnance disposal and qualified in nuclear devices.
Medic	A physician or medical corpsman trained in the biological effects of radiation exposure and the treatment of radioactively contaminated casualties.
Public Information Officer	Trained in the release of accident information to the public news media.
Security	Trained in the protection of classified information and materials.
Laboratory Technician	Trained in radiological sample collection and analysis.
Industrial Hygienist	Trained in the field of radiological and non-radiological toxicity.

*This table lists a variety of personnel that may be utilized on a radiological emergency team. It is neither quantitative nor indicative of minimum requirements. Experience in radiological emergency operations dictates that the number and type of personnel required to handle an emergency situation will depend on the complexity of the situation. This list could also include chemists, physicists, biologists, and many other personnel working in the atomic energy field. However, the list represents those kinds of personnel most likely to be needed in the initial phases of the emergency team operations.

Table 2

Action Guides

1.	40 dpm/cm^2 alpha	Release limit for team members, their material, and equipment.
2.	10 mrad/hr beta and gamma	Release limit for team members, their material, and equipment.
3.	4 dpm/cm^2 alpha "fixed"*	Release limit for all other personnel, their material, and equipment.
4.	1 mrad/hr beta and gamma, known isotope "fixed"	Release limit for all other personnel, their material, and equipment.
5.	0.1 mrad/hr beta and gamma unknown fixed	Release limit for all other personnel, their material, and equipment.
6.	Smearable	Not released to general population.
7.	4 x 10^{11} µCi/cc or 10^2 dpm/m^3 alpha, beta, and gamma	Respiratory protection required. (Field estimate using portable survey instrument at contact with filter, assuming a 50 percent geometry.)

*The term "fixed" means that no evidence of contamination can be detected by swiping a one square foot area and monitoring the swipe with a portable survey instrument.

SECTION 27

EMERGENCY TEAM EQUIPMENT

The ability to monitor and control any radiological accident in any environment is the idealistic aim of radiological emergency teams. There are, however, limiting factors which affect the quantity and type of equipment which can reasonably be transported to the scene of an accident on short notice.

Since time is an important factor in an emergency situation, air travel is recommended whenever possible. Various arrangements for emergency air travel can be made with Federal, military, private, and commercial airlines.

If commercial airlines are used, bottled gas, which may be necessary for some radiation detection instruments, cannot be carried. Another limitation is the amount of baggage allowed per passenger. However, exceptions to such limits may be granted by the airlines in emergency situations.

If private aircraft are employed, they also may have limited baggage space and weight capabilities. Furthermore, private planes are generally used only in remote areas where there are no regularly scheduled commercial flights. These "secondary" airports are often limited in landing and control facilities which may affect utility of private aircraft.

Federal military aircraft, while allowing bottled gas, are generally limited to the larger airfields as are commercial aircraft. However, accommodations for larger loads per passenger can readily be made on military aircraft by using larger planes or reducing the number of passengers.

Another relevant complication is the possibility for an accident to occur in an area entirely inaccessible by any means other than foot travel. In such case, the personnel may have to hike for distances of up to 15 miles (based on U.S. Forest Service estimates). Since few people are conditioned to make such a hike with up to 50 pounds of gear, an airdrop of equipment may be necessary and should be accomplished at a pre-designated spot upwind of the accident scene. Personnel may then have to hike or be flown into the area by helicopter.

If travel to an accident scene is by train, bus, or automobile, the equipment carried must not be too bulky. This will help avoid delays and prevent separation of the team and their equipment for an undue length of time.

Transit time has been comparatively minimized by air travel. A critical element is the time between the notification of an accident and the departure time. Monitoring equipment should be set aside in a designated central location. Personnel who are members of an emergency team should be well informed as to the location and completeness of their equipment. Clearance for removal of the equipment should be readily available on a 24-hour basis. Equipment should have a routine maintenance check schedule to assure its readiness for immediate use and a record should be available to show that maintenance has been completed.

Emergency personnel must be able to respond rapidly. Preparedness requires such things as prior arrangement for finances, clothing, security clearances if necessary, and a meeting place. It is recommended that credit cards or emergency finance reserves be established for this specific purpose.

Company, agency, and military clearances can be arranged through appropriate authorities. Standard agency identification cards should be issued to each team member.

It is recommended that personnel participating in an emergency program have sufficient clothing and equipment to answer a call to any geographic location in the United States. These items should be adaptable to a wide range of weather conditions.

In view of limitations, emergency equipment must meet the following requirements:

1. Be capable of monitoring all types of radiation and contamination hazards (within reason)
2. Be able to function in any environment
3. Be light, compact, rugged and durable
4. Be relatively maintenance free and simple to repair and operate under field conditions

Many companies manufacture radiation detection instruments which meet these requirements. Selection of specific instruments usually depends on specific requirements of a particular organization.

Other items which are needed to complete an adequate equipment list include:

1. Anti-contamination clothing
2. Respiratory protection devices
3. Sample kits, bioassay
4. First aid kits

5. Air sampling devices
6. Radiation barricades and warning signs
7. Rope or ribbon (color - coded)
8. Dosimeters and chargers
9. Record books and notebooks
10. Instrument repair kits
11. Area maps
12. References and tables
13. Containers for contaminated material and samples
14. Masking tape
15. Pens and pencils
16. Flashlights and batteries
17. Camera

The packaging of such a variety of equipment for protection against possible rough handling and the effects of weather presents another problem. Each complete set of equipment may be packed in a separate container using clothing or other soft material for padding. Special suitcases may be obtained for the equipment to specially accommodate the items (Figure 1). In any case, the total weight of the container used and its contents should be limited to approximately 50 pounds.

Examples of items used in a typical emergency monitoring kit are listed in Table 1.

Specific lists of emergency monitoring kits, their agencies, contents and locations, are included, starting on page 27.6.

TABLE 1

ITEMS FOR EMERGENCY MONITORING KITS

QUANTITY	ITEM
Anti-Contamination Clothing (per team member)	
1 pair	Coveralls (Anti-Contamination)
4 pairs	Gloves (rubberized)
2 pairs	Shoe covers (rubber)
2	Head covers (hoods)
1	Full face mask with cartridge
1 roll	2-inch masking tape
(Additional quantities of anti-contamination clothing may be kept in large plastic bags placed near the cases.)	
Radiation Detection Instruments and Accessories (per team)	
4	Alpha detection instruments, PAC-ISA
1	Low-energy gamma detector, ^{239}Pu gamma probe
4	Low-level gamma detector, E-520
4	High-level beta-gamma detectors, PIC-6A (10,000 R/hr full scale)
2	Air samplers (battery operated)
1 box	Filter paper (Whatman No. 41)
1	Dosimeter charger
12	Dosimeters (1R)
6	Neutron activation detectors, (Indium Foils)
6	Flashlights with batteries
12	Spare flashlight batteries

EQUIPMENT

1. ITEM AND LOCATION

a. NV/REECo Equipment

(1) Emergency Monitoring Equipment Kits

Quantity	Location
5 Sets	Mercury, REECo/ESD, H&S Building 650, Room 30. Key for Room 30 is kept at the 24-hour desk at Building 650. Note: Property pass requirements are waived during emergencies for RAT kits and equipment for anyone showing RAT ID card. One kit has a Polaroid camera* w/film and flashbulbs (kit marked).
1 Kit	CP-50, Portable Instrument shop, Room 106.
1 Set	Las Vegas, DOE/NV Building, Room K-217. Note: Polaroid camera* w/film and flashbulb in kit.

*Team member ID card authorizes onsite use during emergency response only.

(2) Instrument Repair Kit

Quantity	Location
1	Mercury, REECo/ESD, H&S Building, Room 30 (Property pass requirements waived).

(3) Radios

(a) Portable Handie-Talkies

1) Team Captain Units--Dual Nets: (2-watt output)
   (1) 171.200MHz*--Captain to captain
   (2) 171.950 MHz*--Captain to team or between team members

*DOE HQ frequencies established for nationwide RAP activities.

Quantity	Location
2	NV/HQ--Rear Gate Guard in charge (carrying cases are in Kit 16A, Room K-217)

2) Team Member Units--Single Nets: 171.950 MHz--Captain to team or between team members

Quantity	Location
4	Mercury, ESD, H&S Bldg., Room 30 (carrying cases on shelf in Room 30)

(b) PORTA-Mobile Unit

Team Units--EPA Net 12

Quantity	Location
2	Mercury, ESD, H&S Bldg., Room 30

(4) Additional Equipment

Any additional equipment required may be obtained on day shift from REECo/ESD, CP-50, telephone 986-2571. For offshift periods, contact the REECo/ESD Field Supervisor on duty and arrange for procurement.

(5) Contents of Kits

(a) Radiation Detection Instruments & Accessories Kit

Type	Model	Range	Quantity
Alpha detector	PAC-1SA (EIC) w/AC-3 probe	0 - 2 x 10^6 cpm	1 each
Neutron/Proton recoil shield	--	--	1 each
High range gamma detectors	PIC-6	1 - 10^3 R/hr	1 each
Low range gamma detector/w Pancake Probe[1/]	E-520 (7 mg/cm^2 w/ tape, 3 mg/cm^2 w/o tape	0 - 20 mR/hr pancake probe) and 0 - 2 R/hr (internal detector)	1 each

[1/] Pancake detector is interchangeable with the standard GM probe of the E-520 chassis; however, the instrument is not calibrated for the HP-177B probe. Note that the pancake probe may saturate at greater than 30 mR/hr. Do not use on X 10 scale.

Type	Model	Range	Quantity
Head phones	---	---	1 each
Micro-R Meter (Scint.)	Ludlum 12S	0 - 3,000 µR/hr	1 each
Std. GM probe	HP-177B 30 mg/cm^2	When used w/E-520 provides 0 - 200 mR/hr (uncalibrated).	1 each
Speaker		Used w/E-520 & PAC-1SA	2 each
Stopwatch			1 each
Air sampler	Lapel	---	1 each
Dosimeters	Bendix	(0 - 5 R	6 each
		(0 - 200 mR	6 each
Dosimeter charger	Bendix	---	1 each
Lantern mantle (taped to inside of lid)			1 each
Business cards (NV-155)			10 each
Flashlight (with alkaline batteries) and extra batteries			1 each

(b) Miscellaneous Gear Kit

Coveralls	2 pair (Ex. Lg.)
Rubberized gloves	4 pair
Rubber shoe covers	2 pair
Surgeon's caps or hoods	2 each
Full face mask (with cartridge)	2 each
Surgeon's rubber gloves	4 pair
Cotton gloves	4 pair
Monitors Handbook (with reference tables)	1 each
Masking Tape (2")	1 roll
Notebook	1 each
Retractable pens	2 each
Marking pencils	6 each
Badge Holders with criticality components1/	6 each
Area access log	1 pad
Radiation survey log	1 pad
Survey grid tablet	1 each
Rand-McNally Road Map Atlas (USA)	1 each
DOE Regional Office Directory	1 each
Filter paper (Whatman 41)	1 box
Nasal swabs	80 each
Swab containers	40 each

1/Film packets can be obtained at NV (Las Vegas) or NTS (Mercury).

(b) Miscellaneous Gear Kit (cont.)

	Quantity
Smear papers	100 each
Glassine envelopes	100 each
Reel of barricade ribbon	1 roll (100 ft.)
Yellow or red (battery-operated) warning flashers	2 each
Contaminated material stickers	25 each
Radiation area signs	5 each
Plastic bags (assorted sizes)	15 each
First aid kit	1 each
Business cards (Radiological Assistance--NV-155)	10 each
Vac-u-sampler	1 each
Tongs (21 inches)	

(c) Instrument Repair Kit

-- needle-nose pliers
-- wire cutters, 4"
-- crescent wrenches, 8" and 4"
-- 3/8" x 7/16" open-end wrench
-- one screwdriver
-- twelve mercury batteries--RM-42R type
-- two mercury batteries--RM--502R type
-- two mercury batteries--E134 type
-- Allen wrench set
-- check sources (alpha and gamma)
-- slip-joint pliers
-- volt-ohm meter
-- Radector (1,000 R/hr) Mod. AG-500-BP
-- E-520B w/Pancake probe
-- PAC-1SA with neutron/proton recoil shield
-- Alpha probe AC-3 w/recoil shield
-- HP-177B GM probe (Spare) not calibrated
-- lantern mantle
-- 50 ft measuring tape

b. EG&G Equipment

(1) Radiation Emergency Kits

Quantity	Location
2	ATLAS Facility (Source Storage Area), Phone 647-5308
1	Escondido Facility (HP Bunker)

(2) Contents (quantity per kit)

Radiological Equipment[1/]

1 PIC-6A High Range Survey Meter
1 E-520 Low Range Survey Meter
w/GM Tube and Pancake Probe
1 dosimeter charger
4 high range dosimeters
6 radiation hazard signs
20 *smears
*barrier ribbon
radiation warning tape and stickers
radiation warning tags

Anti-Contamination Clothing

2 pr. cotton coveralls
2 cotton hoods
2 pr. rubber booties
2 *pr. rubber booties
4 surgeon's caps
1 pr. work gloves
1 pr. goggles
1 pr. plastic coveralls
1 half-face respirator
1 pr. spare filter cartridges
1 full-face respirator
1 spare filter canister
assorted rubber and disposable gloves

Special Equipment

1 roll nylon lacing
1 box Kimwipes
1 roll 2" masking tape
1 roll 2" yellow cloth tape
1 can yellow spray paint
1 can clear spray paint
4 1.5V D cell batteries
4 9V transistor batteries
1 first-aid kit
1 bottle detergent

Tool Kit

1 screwdriver (flathead)
1 screwdriver (Phillips)
1 pr. pliers
1 16 oz. claw hammer
1 10" cresent wrench

[1/]Note: 25 film badges are available at AMS hanger.

*Items also listed under "Equipment Adhered to Lid" category.

Equipment Adhered to Lid

3 flares
2 flashlights
2 pr. rubber booties
2 chemical lights
2 pencils
2 pens
1 black marker
1 flashlight bulb
2 notebooks
1 bomb effects computer
20 smears
barrier ribbon
assorted plastic bags
R.E.M.K contents list

c. EPA Equipment

(1) Emergency Monitoring Kits

Quantity	Location
9	Located in a wooden cabinet adjacent to the Whole-Body Counter Area. (West end (downstairs) of the Administration Building.)

(2) Contents

Emergency kits each contain the following:

1 each Eberline E-500 B
1 each Portable Alpha Counter Scintillation Type
1 set ear phone
1 set of keys to Case
1 stop watch
1 check source (Pu-239)

Also in the cabinet are the following:

1 each Homelite Gas Generator #P/N 705-2351, Unit 3
4 Gas Mask Sets, #045914, 045915, 045916, 045917

Protective Clothing

Coveralls	1 pr 36R
	3 pr 38R
	4 pr 40R
	2 pr 42R
	4 pr 46R

Full hoods	12 each
Surgeon's caps	12 each
Plastic snap-type shoecovers	4 pr
Plastic tie-on shoecovers	3 pr
Cloth gloves	3 pr
Surgeon's gloves size 8	4 pr
size 8 1/2	1 pr
size 9	4 pr
Heavy rubber boots	2 pr
Large booties	20 pr
MSA respirators with ultra filters	4 ea
Extra ultra filters	4 sets
Staplex Hi-vols	3 ea
Tripod	1 ea
4" charcoal imbedded filters	11 ea
4" glass fiber paper	50 ea
Whatman #1 filter paper	5 boxes
Q-tip swabs	6 packages
Masking tape	2 rolls 2" x 60 yds.
Paper tape (glued)	1 roll 2" brown tape
Flashlights	3 ea
Red ribbon	4 reels
Lufkin 100" tape measure	1 ea
Extension cord	1 ea
Clipboards	2 ea

Tools

Pliers-Leach	1 ea
Diagonal cutters	2 ea
Needle nose pliers	1 ea
Knife	1 ea

Plastic Bottles

1 gallon	1 ea
500 ml	2 ea (wide mouth)
250 ml	3 ea (wide mouth)
1 liter	1 ea
500 ml small mouth	2 ea
250 ml small mouth	5 ea

Miscellaneous

Franked labels and envelopes, pencils, plastics, bags, note pads, radiation caution signs, and tapes

SECTION 28

PHILOSOPHY OF RADIOLOGICAL EMERGENCY OPERATIONS

In the context that "philosophy" is an "examination of reasons for fundamental beliefs," the procedures, habits, conventions, and techniques of radiological emergency operations can be subjected to philosophical evaluation. Such an inspection exposes a number of fallacies in accepted tradition. Many practices related to radiological emergency operations are found to be inconsistent with sound philosophy. For example, the purpose, use, and value of the traditional detailed procedures lists become extremely questionable. A comparison of many such lists indicates an almost suspicious similarity regarding the precise detailed action suggested for a team upon arrival at an accident scene. Unfortunately, the lists are too precise to be used effectively as tools. Rather, they prescribe a discipline that might well inhibit a more practical application of effort. For practicality, the team effort must be flexible enough to adapt to existing, rather than theoretical, conditions.

The fallacy of action based on rigidly planned procedures often has been demonstrated in training exercises. Detailed procedures lists, prepared in advance, cannot anticipate all of the conditions that may be encountered in actual emergency situations. Usually the lists are replaced by a few guidelines adapted to observed conditions. Less specific guidelines, addressed to general principles and a flexible sequence for a plan of action, prove to be more useful necessary tools.

In earlier radiological emergency training efforts, actual experience was often limited. Nevertheless, almost without exception, the development and

use of detailed lists of procedures was often characteristic of team preparation. It was somewhat understandable then when one instructor got carried away and said, "if one is going to have a successful accident, it must be well planned in advance."

With passing time there was a development of maturity and experience. The training concepts for Federal agency personnel were expanded and became more practical. In addition, civil agencies such as police departments, sheriff's organizations, fire departments, and Civil Defense organizations become more exposed to training for radiological emergency operations. The training of civil agency groups, oriented primarily to personnel rescue and area control aspects are enumerated below:

<u>Immediate Emergency Procedures</u>

Rescue people, give emergency first aid if possible.

As soon as possible contact closest police or fire department, DOE or military installation or other appropriate agency.

Warn sightseers away from wreckage, containers, spilled materials, other items, and the area involved.

DO NOT FIGHT FIRES except as directed by firemen.

Stay out of smoke, dust or mists resulting from the accident.

Hold for radiation monitoring and/or obtain names, addresses, and phone numbers of all persons who were in the area.

Turn over control only to properly identified authorities.

The "non-specialist" training has become more widespread in recent years. An increasing number of civil agency groups are receiving training to handle general control and safety problems related to radiological emergencies.

The civil agency training effort has helped to crystallize the primary mission of the Federal agency radiological emergency assistance teams. Rescue and traffic control at an accident scene will probably have been initiated by civil agency personnel prior to the arrival of an emergency team. The effort of the specialized team, then, takes up where the non-specialized effort ends. Observations of past occurrences and "dry-run" exercises reveal that several hours can elapse, even under the most ideal conditions, before a radiological emergency assistance team can become functional. Therefore, the emergency team can reasonably assume that rescue, notifications, traffic control, and preliminary safety controls will have been initiated and handled by civil agencies prior to their arrival. This assumption does not imply, however, that the radiological emergency assistance team is relieved of the important responsibility of being able to respond to an accident situation in an orderly and expeditious manner.

Generalized guidelines suffice as a most useful tool for the specialized teams. When tabulated, those guidelines also define the fundamental mission of radiological emergency operations:

Define the radiological problems.
Control the radiological problems.
Document radiological conditions and communicate this information along with significant team actions to appropriate team coordinator.
Assist in restoration of normal operations when requested.

The first guideline is, "define the radiological problem." Liaison with local civil authorities is an important first step and can be helpful in evaluating the status at the site. Liaison with any responsible Federal agency personnel represented, and DOE, DOD, or others will be valuable in developing an estimate of potential radiological hazards.

The next important step in "defining the problem" is to establish a practical exclusion area. Radiological conditions probably will not have been considered by the civil agency personnel at the scene. A word of caution is appropriate at this point. Contrary to what is consistently advocated, this is neither the time for a detailed survey nor is such a survey necessary to "define the problem." Philosophy has definite application at this stage of operations. The "reasons for fundamental belief," relative to radiological operations, particularly the art of monitoring, should be examined in detail.

Notice use of the term "art." Radiological emergency operations training usually does not stress the fact that monitoring is an art. A rather primitive analogy may help establish the fact that monitoring is indeed an art:

> Assume that classes were assembled for intensive study of classical art. Assume also that it were possible to obtain a selection of the "old masters" - from Michaelangelo to Grandma Moses - to instruct the classes. The lectures would deal with perspective, lines, color combinations, continuity, etc.
>
> Now, if the lectures were continued in depth for a sufficient time, all the students probably would emerge as well qualified

art critics. However, if in the final test, easels and paints were distributed with the instruction, "paint a picture," the result would be chaos. Yet, skilled artists, with even less formal instruction create masterpieces that endure the ages.

While art critics are not necessarily artists, they may be able to evaluate a painting better than the artist who painted it. Similarly, a health physicist is not necessarily a proficient monitor although the health physicist may be able to evaluate data better than the monitor who reported it.

Proficiency in the "art of monitoring" is not necessarily gauged, and certainly not replaced, by knowledge of health physics. No amount of instruction can supplant the necessity for practice in the use of radiation instruments for one to become an artist and gather valid survey data. Unpredictable reactions and almost ridiculous evaluations have been observed of radiological emergency team members attempting to be monitors, without having first developed the requisite skill in the art. Panic, confusion, and frustration are not uncommon in such circumstances. Even knowledgeable health physicists, on occasion, have been observed to react strangely and awkwardly when confronted with a complicated monitoring assignment.

There is additional logic for delaying a detailed survey until the "emergency" climate has stabilized. The complexities involved in performing even a brief gamma survey, in the early hours following an accident, can tax the skill of the most experienced monitor. If, additionally, there is a dispersal of an isotope such as plutonium-239, a great deal more time will be required to develop and apply the necessary and extremely rigid

contamination control procedures before a detailed survey can even be initiated.

Time is of the essence in the early hours following an accident. Therefore, initial monitoring should involve only gross hazard evaluations, and isolation and definition of the radiological problem areas and the clean areas. Necessary evaluations can be made quickly. External exposure areas can be easily evaluated during a cursory gamma survey. Similarly, if plutonium-239 is a problem, the boundaries of the contaminated area also can be quickly defined - either by an alpha survey, or a low energy (17 keV) gamma survey. Also, visual inspection of the debris strewn area will often provide valuable clues as to the general shape of the most highly contaminated area. Thus, the problem areas are defined and the stage is set for the second guideline of the basic mission which is "control" of the radiological problems.

Only after the "clean" and contaminated areas are defined, can practical and effective control measures be initiated. Also, when this information is known, restoration of normal operations can be initiated to "get the place in business again." Relaxation of emotional pressures will be observed as some degree of normalcy is restored. Then, more time will be available to develop appropriate contamination control procedures. Careful attention should be given, during development of these procedures, to provide for complete quantitative and qualitative documentation of the accident situation and the actions taken.

Once suitable contamination control procedures are initiated, there should be a philosophical examination of not only what should be done, but also what can be done with the available equipment, time, and facilities. If the

radiological problem is simply one of external radiation, a complete assay of the controlled area can be obtained in a very short time. The techniques are straightforward enough that further discussion is not warranted here. However, if plutonium-239 is a problem, completely different and extremely complex circumstances may be expected to emerge. The problem becomes clouded by so-called "magic numbers" and erroneous concepts that have crept into literature dealing with radiological emergency operations.

There are those who advocate that reliable, quantitative data relative to finely divided, widely dispersed, freshly deposited plutonium-239 can be obtained in the field with presently existing survey equipment. Many people believe this erroneous idea should be completely abandoned. Actually, nothing more than gross estimates are possible. The ubiquitous nature of such contamination, at least until stabilized by time and natural forces, absolutely defies description. Anyone who has experienced an attempt to quantitatively assay, with portable radiation instruments, a fresh dispersal of plutonium-239 will quickly confirm that the most that can be accomplished is gross contamination of self, instruments, and ultimately, the "hot line" control set-up. These conditions, philosophically examined, support the position that a requirement for a "detailed survey" has no place in procedures followed during the early hours of an accident situation.

Other circumstances raise a question as to the value of any quantitative estimates based on a direct instrument survey of dispersed plutonium-239. Habits peculiar to individual monitors, particle size of the emitting material, surface configuration, and forces of nature, all will have some affect on radiation instrument response to alpha radiation. There is no

practical way, under field conditions with existing equipment, to accurately evaluate the total effect of such influences. Therefore, any attempt to do more than roughly estimate the relative magnitude of the contamination problem by direct survey is a waste of time. One who advocates that field survey instruments can be used to determine accurately $\mu g/m^2$ of plutonium-239 contamination reveals himself to be something less than knowledgeable in the art of monitoring. The use of a survey meter in such a situation is, for all practical purposes, limited to the following:

The area of negligible contamination
The area of nuisance contamination
The area of gross contamination

For quantitative determinations of surface contamination, carefully collected, representative soil samples and debris samples must be submitted for laboratory analysis. Similarly, carefully selected aerosol filter samples must be submitted for laboratory analysis to provide the airborne contamination data required for documentation. All such samples must be carefully identified.

Personnel radiation exposure control should be considered carefully throughout operations. The limits established for radiation workers should not be exceeded in normal operations. If exposures higher than 25 R are necessary to save life or to carry out some other essential act, volunteer assignments should be permitted. The circumstances should be evaluated with the most discretion possible at the time. Permission to take an acute dose exceeding 100 R should be withheld except to save human life.

The next guideline in the basic mission involves "documentation and communication." It should be borne in mind that while the primary mission is to

restore normal operations, the responsibility of documentation and communication should be made known to every participant. Sampling and survey procedures for quantitative determinations should be periodically reevaluated as clean-up progresses. Representative soil samples, surface soil smears, and debris should be collected prior to and during the clean-up operations. Personnel exposure conditions should be documented carefully throughout these operations.

The importance of a sophisticated thorough assay program assumes increasing "after the fact" significance. A full scale documentation effort can be implemented in a manner that will not delay or seriously affect the ultimate goal, which is to define the problem and restore normal operations.

Of equal importance is the necessity for communication of findings and team actions to responsible agencies through the team coordinator. Since the team can be considered an instrument of a higher authority, its effectiveness can depend on proper liaison with such authority. The last guideline and the ultimate goal of emergency operations is the restoration of the distressed area. In many instances, the team will be called upon to assist in decontamination efforts with the agency that is responsible for the radioactive material. After the "negligible contamination" area has been defined, there is a logical sequence of operations to clean-up and progressively restore normalcy. The team will converge toward the central problem area as survey and clean-up operations are initiated. A word of caution is warranted because during clean-up the control of contamination becomes increasingly difficult. Vehicles, equipment, and personnel that have left the area before emergency control was established must be located, monitored, and decontaminated. In

fact the clean-up problems outside and remote from the controlled area may be more difficult and more sensitive than those at the site.

The radiological emergency team can make its most significant contribution during the clean-up phase of the mission. Sensitive, enduring problems can be generated by inept handling. In general, the clean-up techniques should proceed in accordance with recognized health physics principles. This philosophical review of radiological emergency operations has in part described the specialized role of the radiological team and indicated its need for cooperation with other participating agencies. The need for a flexible capability responsive to existing rather than predicted conditions has been examined.

These considerations have established sound reasons for believing that radiological emergency team training should strongly emphasize specialized training and practice that will aid team members to define, control and eliminate radiological problems and to maintain both personnel and equipment in a constant state of readiness.

SECTION 29

PUBLIC INFORMATION IN RADIATION ACCIDENTS*

I have changed my assigned subject from "Public Relations in Radiation Accidents" to "Public Information in Radiation Accidents" for a reason I believe to be important. The term "public relations," rightly or wrongly, has for many people the connotation of attempting to influence people rather than to inform them. This, of course, is not the proper business of a Government agency. The function of a Government information man is to provide useful facts to the public news media as quickly, as completely and as accurately as possible, and not to attempt to control opinions about those facts.

This may sound as if I were taking a firm stand against sin, but I believe that it also is enlightened self-interest for a Government agency, or a contractor engaged in Government work, to present facts objectively rather than to select or arrange them in an attempt to influence attitude or opinion. The temptation to avoid criticism or embarrassment by telling only part of the story, or by sugar-coating it, can be strong. This temptation, however, should be firmly resisted in connection with any work that is financed by money from the general taxpayer. The embarrassment involved in admitting an error candidly is small compared to that which results if you are caught trying to hide or minimize it, and your attempted evasion is held up before

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the public. A radiation accident, for example, is an unpleasant fact of life which must be faced up to. There is no public relations magic that can make it fade away, or reduce the legitimate interest of the news media in telling the public about it. The most important idea that I hope to leave with you is that the best way to handle the informational aspects of such an accident is simply to tell the truth about it. The comforting corollary is that the truth about a radiation accident is almost certain to be much less alarming than the exaggerated ideas which will spring up in people's minds if an atmosphere of mystery about the accident is created. Public announcement of the facts will reduce public alarm and increase public understanding. In other words, good public information practices beget good public relations.

I have been in the Public Information Service of the Atomic Energy Commission since early 1952. My work has given me a good vantage point to observe the public reaction to the radiation accidents which occurred during that time, and to try to figure out why the public reacted as it did. I am tempted to postulate that there is an inverse relationship between the magnitude of an accident and the public reaction to it; in other words, the less serious the accident, the more intense the public concern. I suspect that this is not really a natural law, but it has been startling at times to see how much alarm has been aroused by a relatively minor accident, and on the other hand the calm with which some relatively serious ones have been accepted. In the course of these remarks, I hope to suggest some of the reasons why little accidents can cause big headlines, and how to keep them in perspective.

The public information handling of an emergency situation is part of the whole complex of decisions which must be made to meet the emergency. These decisions affect each other. An unwise operating decision inevitably will make the public information task more difficult. Conversely, poor public information procedures can cause serious interference with measures necessary to alleviate the emergency.

The decisions involved in any crisis are difficult. Actions must be performed quickly and under extreme pressure, yet the consequences of poor judgment are likely to be very serious. Normal procedures must be shortcut or abandoned. Confusion is paramount - it is hard enough to ascertain the facts, let alone to decide what to do about them.

All of these difficulties are compounded several times over when radioactivity is present. I am sure that such operational decisions as how to care for casualties or whether or not an area should be evacuated must be greatly complicated by the presence of radioactivity. Similarly, the public information problems are made much more difficult. For one thing, many people do not react at all rationally when the word "radioactivity" is mentioned. This is not necessarily to their discredit. Radioactivity still is a new and mysterious phenomenon to most people. The very fact that it cannot be detected by the unaided senses makes it more frightening. It is inevitably associated with nuclear warfare, and the fears and anxieties concomitant with life in this shifting and uncertain world, in which science seems to many to be an evil genie rather than a helpful servant, find a focal point in the specter of radiation. A few months ago, a public opinion research group reported on the results of a nationwide survey of teenagers to

determine their attitudes toward atomic energy. Nearly all of them associated it with warfare rather than peaceful applications. Ninety percent of these young people said that they expected that nuclear energy eventually would destroy the human race. Only 39 percent said they were glad that nuclear energy had been discovered. The atomic energy industry has achieved a remarkable safety record, but the relatively few accidents which have occurred have assumed exaggerated importance because of such emotional reactions. Fears about fallout have added fuel to the flame. What are the connotations of radioactivity in the public mind? Mysterious, invisible danger, striking without warning, causing death or dreadful illness, premature aging, sterility and the malformation of children through many generations. As a result, primitive, almost instinctive fears are awakened by this new force unleashed by modern science. No, it is not surprising that people are afraid of radioactivity.

The aura of almost superstitious fear surrounding radioactivity greatly complicates all aspects of meeting a radiation emergency. Recognition of this fear also points toward what is perhaps the most important and most difficult part of the public information task. This is the work that is done, not after the emergency actually has occurred, but in the months or even years preceding it. It is the work of public education.

Despite our level of technology, most people in this country today would have a hard time explaining how an electric motor works. I know that many people drive an automobile daily with only the most rudimentary idea of what makes it go. Thousands of people entrust their lives to airlines without any understanding of how something heavier than air can fly. Yet,

most people are not unduly afraid of electricity or gasoline engines or airplanes because they have a good idea of the magnitude of the risks involved in their use, even though they may not understand the principles involved.

Similarly, we don't need to turn ourselves into a nation of nuclear physicists to achieve adequate public understanding of radiation hazards and the safeguards against them. What is chiefly necessary is to bring people to the understanding that radiation should not be thought of in simple black or white, "is" or "is not" terms, but rather in such relative terms as "how much," "what kind," "at what rate" and "for how long." When people are capable of grasping the quantitative nature of radiation hazards, rather than believing that the mere presence of any amount or kind of radiation is deadly, they will have gone a long way toward viewing the hazard in proper perspective.

If a radiation accident occurs at a particular facility, the reaction of the local public will depend to a considerable extent upon whether or not they have previously been exposed to a public education program about radiation. Educating the public in a new technical field is a long, slow process. No single Government agency or private organization has the resources to conduct the massive campaign which would be necessary to make a deep and lasting impression on the public consciousness. Many millions of dollars are spent by advertisers each year on such relatively simple tasks as promoting the sale of a particular brand of soap or cigarette. The task of educating the public about radiation is much bigger and more difficult. Private firms engaged in nuclear energy projects, or using radioactivity in one way or another, can assume part of the job. Some are doing so, and

I hope that eventually every firm using radioactivity will recognize that it is simple self-protection to educate its local public before an accident occurs, rather than to engage in frantic and probably ineffectual reassurances after the fact.

An important part of the educational job must be taken on by volunteers. By this I mean people like yourselves. Every time you make a speech before a local Chamber of Commerce, Lions Club or school, and every time you take the trouble to explain the facts of radiation to a newspaperman or magazine writer, you are performing a real public service.

It is a mistake to be critical or contemptuous of the average newsman because of his lack of knowledge of your field. A good newsman is eager to learn and has the same respect for facts that a scientist has. But until recently, specialists were a luxury that only a few metropolitan newspapers thought they could afford. Fortunately the situation is changing, although there is still a long way to go. The September 1959 issue of The Quill, the magazine of the professional journalistic fraternity, Sigma Delta Chi, states in an editorial:

> "A generation ago any reporter worth his salt was confident that he was competent to cope with whatever assignment came his way, whether it was a general alarm fire, a juicy murder, or interviewing the latest literary lion . . . A good reporter could take all types of assignments and come up with a story that would pass muster on the city desk . . .

> "In that day only the great metropolitan newspapers could afford the luxury of a . . . full-time specialist in any field. Today, even in the smaller communities, it is just as true that a paper cannot afford to be without specialists in at least some fields . . .
>
> "It is an acute problem for the metropolitan paper, even with all its resources in manpower and money. It becomes a more difficult problem on a smaller paper where both manpower and financial resources are limited. Yet it must be solved if the press is to continue to fulfill its function of informing the people and helping them understand the significance of the news . . . "

In almost any community near a plant or laboratory where radioactivity is produced or used, there are likely to be one or more bright young newsmen eager to learn something about atomic energy. If there are enough of them, news seminars can be held with profit. In such educational sessions, the newsmen not only should be given general information about radioactivity, they should also be briefed as candidly as possible on the possible radiation hazards at the particular facility and the safeguards taken against these hazards. Properly handled, such briefings can be reassuring rather than alarming. I repeat that the facts about radiation are less frightening than the specters conjured up by imagination.

I have devoted so much time to public education before an accident occurs because I believe it is at least as important as, or possibly more

important than, the actions taken after the accident happens. Now, let us assume that an accident has occurred. Let us assume that neither the local public nor the local news media knows much about radiation hazards, since this probably would be the case.

Various kinds of radiation accidents are possible, of course. The accident may occur in a Government facility, a contractor facility, or a privately owned and operated facility. It may occur during the transport of radioactive materials by truck, train, plane or ship. There may or may not be a release of radioactive materials to the environment. The public may or may not be exposed to hazard.

From the public information point of view, the simplest radiation accident is one restricted to the confines of a remote installation, with no possibility of danger to the public. In such an accident any people involved are on their regular working premises, and familiar routines and procedures will be applicable to some extent. Also, since the accident is inside the installation, the officials involved have unimpeded opportunity to prepare to make the accident public in proper perspective. Public hysteria is not likely to occur when it is made obvious that the public is not endangered.

This kind of accident, however, sets a dangerous public information trap for short-sighted management. Since the accident is not immediately apparent to the public, there is a temptation to sweep it under the rug and not announce it. It is very easy to produce all sorts of rationalizations

radiation accident. No one may have been seriously

overexposures may have occurred. Of course, some

judgment must be exercised; there is no point in issuing an announcement every time there is a laboratory spill. Nevertheless, I am convinced that the surest way of turning a minor radiation accident into a major one, through speculation and rumor, is to fail to announce it fully and promptly. This is true particularly if a reactor in involved.

Any significant mishap to or malfunctioning of a reactor, whether or not radioactivity is released, is news today and in the foreseeable future. There are a number of capable and determined reporters covering the atomic energy program, and sooner or later one of them will hear about it. It doesn't matter then how innocent may have been the intentions of the people who decided not to make the announcement. Their motives immediately become suspect, an aura of mystery and concealment is thrown about the accident, and it lands on the front pages as a sensationalized disclosure. Since even minor accidents may have aspects which make them newsworthy, it is best to obtain the counsel of experienced public information officials before deciding whether or not one is significant enough to be made public.

Of course, many accidents occur under circumstances which make them known to the public almost immediately. For example, a truck carrying radioactive materials may overturn on a public highway. An explosion may occur in a plant in or near a populated area, under circumstances which require that local fire and police departments must be called into action. In such instances, the news media and the public quickly become aware that an accident has occurred and they may have a totally erroneous initial impression of the public hazard. This erroneous initial impression will spread like wildfire unless immediate action is taken to counteract it.

There is risk that panic among the public will cause more serious hazards than the accident itself, and will interfere with the measures necessary to bring the emergency under control. An even more extreme situation would be an accident involving genuine hazard to a local population, such as release of significant radioactivity to a populated area. No major radiation accident of this nature has occurred in this country, and we all know that the possibilities of one are extremely small. However, it is apparent that plans must be made to meet even such remote possibilities.

The closest we have come to the public information problems which would be created by an accident of this nature was a situation which actually involved no significant radiation hazard at all. This was the explosion of a thorium compound at the Metallurgy Laboratory of Sylvania Electric Products, Inc., at Bayside, Long Island, on July 2, 1956. This accident did not cause any public hazard, and it did not create significant radiation hazard even to the employees of the plant. Nevertheless, for some hours many thousands of people had the impression that a major radiation accident, involving possible hazard to the public, had occurred. For this reason, the Sylvania accident is the best case history we have to indicate the public information problems which would accompany a serious radiation accident involving possible hazard to the public. It also illustrates the factors which tend to magnify an accident involving possible hazard to the public. It also illustrates the factors which tend to magnify an accident to many times its proper size simply because of the real or imaginary threat of radioactivity.

As you probably recall, the Sylvania accident occurred when plant employees were engaged in burning thorium material for conversion to oxide.

An explosion occurred when a small piece of the thorium material was placed under a burning hood. This was followed by one or possibly two other explosions. Physical damage was largely confined to the room in which the men were working, and was estimated at about $25,000. Nine employees were injured, four seriously enough to be hospitalized. One of these men later died. The injuries were from blast and burns, and there was no serious radiation exposure or ingestion of radioactive materials. Outside the building, there was no detectable radioactivity above background.

The accident occurred at 8:40 a.m. By 9:30 a.m., there were four complete TV newsreel crews, 15 newspaper and wire service reporters and 10 news photographers at the site, and news aircraft were overhead, taking aerial photographs. Telephone inquiries from news media were pouring into the Commission's New York Operations Office, and several reporters had arrived at the office to cover that end of the story. At about 10:30 a.m. one of the radio-TV networks advised the New York Operations Office that its switchboard was jammed with calls from Bayside residents asking whether or not they should evacuate the area.

The Commission's New York Operations Office and the Sylvania Company did a fast job of getting known facts to the public. At 9:15 a.m., 35 minutes after the accident, a statement was issued that is was non-nuclear in nature. An hour and a half later, it was announced that no radiation hazard existed outside the building in which the explosion had occurred. At 1:30 p.m., it was announced that the material involved was thorium, and it was emphasized that thorium is only mildly radioactive and has been used in non-atomic industrial processes for many years. AEC and Sylvania officials

stated that there was no danger of radioactivity outside the plant and that any contamination inside was negligible.

Despite these reassurances, the afternoon papers in the New York area carried banner headlines on the accident. Typical ones - in type two inches high - were: "300 Tested for A-Blast Poison," "Blast in Queens Atom Lab," and "Blast Rocks Queens A-Lab, 9 Hurt, Rays Hit 45 Firemen."

Nearly all of the initial stories emphasized that threat of radioactivity. Typical statements were that the danger of contamination "was so acute" that specialists from the New York Health Department's radiological unit were dispatched from Manhattan, that 45 firemen had been contaminated, that firemen and Sylvania employees would undergo hospital tests to determine whether they had suffered radiation effects, and that more than 300 people had been exposed to radioactivity.

Before one criticizes the newspapers for this treatment of the accident, it should be recognized that the news stories were not figments of the reporters' imaginations, but were based on information which had been given to them. For example, reporters learned that soldiers had been sent from nearby Fort Totten to help control the emergency, that 10 doctors had been sent to the scene by the Army and Navy, that radiological experts had been dispatched by the Atomic Energy Commission and the New York Health Department, and that the 300 employees in the building had been directed to go home, bathe thoroughly and report later to company physicians for medical examinations. Fire officials said that 45 firemen had been contaminated in one degree or another, and that they would be tested for radioactivity

Four firemen and more than 20 policemen were hospitalized for observation. Work clothing of employees was collected after the explosion, and employees who had left the site were instructed by telephone or telegram to bring clothing in. The lunch for Sylvania employees, which was in a building about 200 yards from the explosion site, was thrown away. Policemen cautioned mothers in nearby residential areas to keep their children inside.

Reporters could not ignore these actions - they were a legitimate part of the story. Undoubtedly this flurry of official activity gave the reporters the impression that a big story had broken, and that significant radioactivity had been released. Straighforward reporting of what was happening at the accident scene could hardly help but give the public the same impression.

Along with facts of the kind mentioned above, the news stories also carried the reassuring information provided by the AEC and by Sylvania. As a result, the stories had contradictory elements: they included official statements that there was no significant radiation hazard, and at the same time reported official actions that inevitably gave the impression that such a hazard did exist.

Remember that the job of a reporter covering a spot news story is to report, not to interpret or select facts. He will go to various sources which are considered to be authoritative, and will report what he is told by such sources, even if some of the statements appear to be contradictory. He will also report what he sees as well as what he is told. This is his job, and there is no reason to criticize him for doing it.

Even though the public undoubtedly received an exaggerated impression of the Sylvania accident on the day it happened, the quick action to report the facts as candidly as possible had the healthy effect of making the story a one-day wonder. The stories the next day were entirely different in tone. Typical headlines were: "Doubt Radiation Hurt A-Victims; Queens Workers Will Undergo Checkup to Reassure Them;" "No Radiation Peril in Labs, N.Y. Area Told; Installations Can't Release Dangerous Amount, AEC Says," "AEC Denies City Faces Radiation." and "Firemen Unharmed in Blast, AEC Says." If the AEC and the company had not provided information as quickly and as completely as possible, I am sure the story would have built up rather than decreasing in news value.

Since the Sylvania accident occurred, there have been two radiation accidents which involved much more serious radiation exposures, but which received much less sensational treatment by news media. One was the Y-12 accident at Oak Ridge, in which several persons received significant doses of radiation. The other was the accident at Los Alamos Scientific Laboratory, which resulted in the first radiation fatality in the Atomic Energy Commission's history.

As I said a few minutes ago, the handling of accidents in remote, relatively self-contained installations is simpler in some ways than coping with a situation such as the Sylvania accident. This is part of the reason for the sound, unsensational news treatment of the Y-12 and Los Alamos accidents. Both of these accidents were in localities removed from an active metropolitan press. Also, they did not involve fire or other physical damage which would have required the presence of local authorities. As a

result, there was only one source of official information and reporters were not present at the accident scene. Nevertheless, if information on these accidents had not been issued promptly and candidly, there is little or no doubt that they would have ultimately reached the public as sensational disclosures of suppressed information. In each of these accidents, the news media felt that they were being dealt with straightforwardly, and that the facts were being given them as soon as they were obtained. As a result, they wrote their stories factually, and did not attempt to build up an atmosphere of mystery or charge that facts were being withheld.

There have been several other radiation accidents which are interesting from the public information point of view. Examples which come immediately to mind are the M. W. Kellogg Co. accident in Houston, Texas, in which several employees were exposed to radiation and in which radioactive materials were tracked into several homes, and the incident in Connecticut which involved the picking up of a cobalt-60 radiography source by an employee. Both of these incidents had dramatic story elements and involved the possible exposure of the public to radiation. As a result, they received extensive coverage by news media and both were dramatized on nationwide television programs. These accidents are of interest to the Commission because they point up the problems involved in informing the public about radiation accidents in facilities which are privately owned and operated, but which are licensed by the Commission to handle radioactive materials. Obviously, the Commission has the responsibility to provide certain information to the public about such incidents, but the Commission's public information responsibilities are modified when incidents occur in facilities

which are privately owned and operated. We have given considerable thought to the problems resulting from such incidents. I am not going to analyze them in detail here. Rather, I would like to make some generalizations which I believe apply to the public information handling of virtually any kind of radiation accident.

1. The news media treatment of an accident, and the public reaction to the accident, depend to a considerable extent upon what has been done before the time of the accident to educate the public about radiation in general, and about the specific hazards of the particular operation and the safeguards taken against them.

2. An important aspect of this educational effort is the informing of local news media and of local authorities. Local firemen and policemen should be made aware of the potential hazards at the installation, and also should be advised what hazards are not present. For example, if no serious radiation hazard can be expected from the materials involved in a certain operation, the local authorities should be aware of this so that they will not unduly alarm the public by taking unnecessary precautions in the event of an accident. It should be remembered that the statements of local authorities will have an important influence on the news treatment of an accident. Reporters are accustomed to working with the local fire and police officials, and they will naturally go to them for information.

3. A disaster plan should be worked out in advance. It should cover much more than just the public information aspects of the emergency, of course, but the public information aspects should be an important part of

the overall plan. The advance planning should include determination of the hazards to be expected in the event of accident, and what can be said publicly about them. It could even include the advance preparation of "canned" statements for use under certain circumstances.

4. Get the information out as quickly as possible and as completely as possible. If classified information is involved it must not be compromised, of course, but classification should not be used improperly to avoid giving out embarrassing facts or as dishonest justification for less than adequate statements. It is better to admit an error than to be forced to confess it under the pressure of newsmens' disclosures.

5. Work with the reporters, not against them. Remember that they are very likely going to get a story whether you like it or not. If the responsible officials will not give them the facts, they will go to other sources. In the absence of official information, they will be forced to reflect rumors and exaggerated or distorted information, or they may speculate. An accident is an unpleasant fact of life. There are no known public relations techniques that will make it disappear, or reverse time and make it unhappen. The best that can be done is to face the facts and strive to keep the news stories and the public reaction in proper perspective.

6. Be sure of the facts before they are issued. Do not be drawn into making statements that may have to be retracted later on. Avoid being led into speculation or comment on hypothetical situations. In the early hours of an accident, many facts will not be known. This should be stated in response to reporters' questions, and the reporters should be assured that additional information will be provided as quickly as possible.

7. Remember that the really fast media are the radio and television stations. In any major accident, they are likely to be on the air with whatever information they have hours before the first newspaper accounts appear. The early public reaction to the accident will be molded chiefly by the radio and television broadcasts, and it is vital to get information to these media to prevent undue public alarm.

8. Make sure that the information issued publicly is consistent. The best way to achieve this is to have only one spokesman in dealing with the news media, and only one point of primary issuance, unless reliable coordination of more than one spokesman can be accomplished. If an experienced public information officer is available, the information should be channeled through him, although he may find it advisable to call upon operating officials to appear at news conferences under certain circumstances. Keep information flowing to the spokesman; he can serve an important function by minimizing undue public alarm and also by keeping reporters out of the way of the people handling other aspects of the emergency. Make sure that the local officials are receiving at least as much information as the news media, and not later than they do. It may be advisable to issue all information through the local officials; they are likely to be known and trusted by the local news media. On the other hand, it may be necessary to issue statements supplementing those of the local authorities.

9. If the accident is away from the normal issuance point for news, keep communications open between the accident site and your home installation It may be necessary to issue information not only at the accident scene, but

at another point more accessible to the news media. In such circumstances, make sure that the same information is being issued at both places.

10. Remember that any action taken during any emergency may be reported publicly and may have considerable influence on the news treatment of the accident. Of course, necessary actions will have to be taken whether or not they produce bigger headlines. However, the possible public reactions should make the operating officials weigh each action carefully before proceeding, to make sure it is really necessary. In any radiation accident, the tendency probably will be to take extra precautions to protect health and safety, and it should be made as clear as possible to the news media that these are precautionary measures and do not necessarily mean that an actual danger is present.

11. Whenever possible, it is best to rely on the judgment of experienced public information officers. If possible, they should be part of the initial team reaching the site of an accident. If they cannot be at the site, they can probably be reached by telephone. It is true that public information is an art, not a science, but an experienced information man knows news media needs, can judge news media reactions, and will act correctly almost by instinct most of the time, whereas an inexperienced person could do the wrong thing just as instinctively.

The Atomic Energy Commission has given responsibility to eight of its Operations Offices to provide radiological assistance in the event of a radiation accident. These Operations Offices have established radiological assistance teams which would respond to accidents in specified areas. Each

office has drawn up a radiological assistance plan, and each plan has a section on public information. These sections are generally consistent with the principles I have stated above.

In addition to responsibilities for assistance in the event of accidents involving the peaceful uses of radioactive materials, the assistance teams are included in a nation-wide network established by the Albuquerque Operations Office of the Commission to handle accidents involving nuclear weapons. The Department of Defense also has established a system of teams for weapons accident emergencies.

As you probably know, the AEC and DOD have issued an information bulletin on atomic weapon accident hazards, precautions and procedures. This bulletin has been widely distributed to local police and fire department officials, to state officials, to military field commands and to the news media. The bulletin explains the stringent safety measures are taken in the design and transportation of atomic weapons, and states that they are designed to preclude a nuclear explosion in the event of an accident. It points out that the probable hazard from nuclear weapons accidents is commensurate with the hazard from conventional weapons and materials, and would consist chiefly of the possible detonation of high explosives and the possible release of plutonium. The bulletin states that safety restrictions have been placed on the number of atomic weapons per shipment, so that the plutonium inhaled from an accident would not result in serious injury. It describes procedures for the notification of the proper authorities in the event of a weapons accident and describes emergency actions to be taken.

Issuance of this information should help to prevent undue alarm in the event of a weapons accident. The local authorities should be aware that the principal hazard would be from conventional high explosives, and not from a nuclear detonation. Classification rules would prevent the issuance of many details about the accident, but information on the degree of public hazard almost undoubtedly could be released in unclassified form. There is no question that such an accident could create considerable local public alarm. However, any weapons accident will quickly bring into action a detailed plan for meeting all aspects of the emergency, including the informational ones, and there is no necessity for me to discuss the problems in further detail here.

I hope that I have given you some feel for the public information problems which will arise in the event of a radiation accident, and an indication of some of the ways to meet them. Obviously, it is a lot easier to make a speech about what to do than it is to do it in a real emergency. The essence of an emergency is that things do not go smoothly or in accordance with routine. Procedures must be modified to suit the circumstances, and there just isn't time to do everything that should be done. However, the following of sound public information principles can make it easier to bring the emergency under control, can prevent unnecessary and possibly dangerous panic, and can help to prevent public repercussions which could be more serious than the radiation accident itself.

SECTION 30

LEGAL AND PRESS RESPONSIBILITIES

A degree of familiarity with the legal and public information aspects of radiological emergency incidents is necessary for all members of a radiological emergency team. Although these complex subjects require the attention of specialists, each member of an emergency team must be familiar with certain pertinent factors.

Legal Responsibilities

Each team member is considered to be acting as an official representative of a U. S. Government agency, and his legal responsibility is essentially the same as in his normal duties. *No team member has police or legal powers over public or private property or private citizens.* This limits the action which team members can take at an incident scene that is not located on Federal property. Under the Constitution of the United States, the individual state is responsible for maintaining control and protecting the life and property of its residents. Therefore, any Federal agency emergency team must depend upon the local authorities for confiscating property, entering private land, or in any other way, infringing upon the rights of the public. In most cases local authorities are ready and willing to cooperate.

Entrance to private property is controlled by the property owner. The only people who can enter without the owner's permission are local or Federal law enforcement and health agencies and, in some cases, Federal agencies such as the FBI. Members of the DOE or military may not enter property without proper permission.

The only exception to the above rule is when an extreme disturbance or disaster has taken place. In this situation, the President is authorized to declare martial law or institute other types of Federal control, thus assuming responsibility.

If an unauthorized person at an incident scene has taken photographs of classified material, and will not voluntarily surrender the exposed film, the only recourse is to inform the offending individual that the possession of such items is in violation of Federal law as stated in the following statutes:

18 USC 793 (e) Unauthorized possession of or control over classified matters, including photographs, maps, and other items which the person willfully retains and fails to deliver upon demand to an officer or employee of the United States authorized to receive it, is punishable by a fine of not more then $10,000 or imprisonment of not more than 10 years, or both.

18 USC 795 The act of taking or making any photograph, pictures, maps, or other representation of vital military and naval equipment without first obtaining permission of the military commander authorized to give permission is prohibited. This offense is punishable by a fine of $1,000 or imprisonment of not more than one (1) year, or both.

If, after being informed of the above statutes, the private citizen still refuses to relinquish the material, the team member must notify the FBI or civil authorities to have the material confiscated. The camera, negatives or prints may never be taken by force. Neither can physical force be used to prevent the taking of pictures.

If a private individual is in possession of Government property, classified or unclassified, the team member may not take it without the individual's consent. If the person refuses to give it up after being informed that he is violating the law, civil authorities must be contacted.

Entering into a contaminated, explosive, or otherwise dangerous area by a private citizen on his own property, cannot be forcibly stopped by an emergency team member. The individual can only be informed of the danger (in the presence of witnesses if possible) and, if he insists, must be allowed to enter. Again, however, civil authorities could prevent his entry.

The private property of a person may never by confiscated without his permission, unless taken by lawful authority. This holds even if the property is highly contaminated and presents a hazard.

As narrow as the above limits appear, there are a few things an emergency team member can do predicated on his being a private citizen and a Government employee. Persons observed in the act of removing Government property from the scene may be prevented from doing so by the use of force, if necessary. A "ticklish" legal problem arises here. The law states that as much force as necessary may be used. Discretion must be used in this type of situation to avert charges against the team member and the Government.

The "citizens arrest" is another avenue of approach that is theoretically open to the team member. The law says that a private citizen may make an arrest only when a felony is observed being committed or when having direct knowledge that a felony has been committed and when having reasonable grounds for believing that the arrested individual actually committed the crime. A felony is generally defined as a crime that is punishable by

imprisonment for more than one year in a state or Federal penitentiary. For one's own protection against false arrest charges, "citizens arrest" should never be used except as a last resort and then only if one is absolutely sure that he is right. Note that this may differ according to state laws.

In any accident situation where claims or damages may later be made against the Government, the emergency team should be prepared to testify on the validity of such claims. Whenever faced by claims resulting from accidents, the Government is invariably forced to pay an amount of money, sometimes in excess of the true value of the damaged property. Therefore, the team should attempt to record a true and fair value for damaged items and the extent of damage at the accident scene.

Public Information

If a major accident occurs, with public safety implications, the plan is to issue a statement as soon as possible (see announcements at the end of this section) and to follow up with elaborating statements as quickly as additional facts can be learned.

Primary responsibility for public reporting in event of an accident falls upon the organization having custody of the material involved. That is, should a DOE team respond to an accident involving radioactive material in U. S. Army custody, the Army has primary responsibilities for releasing information to news media. Queries from newsmen should be directed to the responsible organization.

Public reaction following an accident (both locally and widespread) can be strongly influenced by official public reporting. Public reaction can be a

very important aspect of accident control. From the long-range viewpoint, unfavorable public opinion resulting from an accident can result in a loss of public confidence in the controls existing in the nuclear industry.

In the event of a major accident, a primary objective of the public information officer is to do what he can--through the news media--to publicly report the facts as promptly and completely as possible within the framework of security requirements. This will reduce the possibility of panic that could result from irresponsible and erroneous news media speculation.

How does the public information officer do this?

A serious accident immediately produces the requirement for "spot" news or "hard" news. Media representatives are vigorously seeking information to meet publication and broadcast deadlines. As soon as he is identified as a news source, the public information officer becomes the focus of news media attention.

With very rare exceptions, reporters are responsible newsmen who demonstrate varying degrees of journalistic initiative. For "hard" news, they prefer facts to speculation. Also, they share your sensitivity to the security facts of life--but they will resent any effort to hide the unclassified facts under a security blanket. A basic objective you are seeking is the *confidence* of the newsmen.

A primary rule to observe with newsmen is to report to them promptly, honestly, and as completely as possible. If you don't have an answer to a question, admit it--and explain that you will try to get the answer as quickly as possible. A responsible newsman will understand. But don't

deliberately lie to cover an inability to provide information.

Some nuclear problems are particularly subject to misunderstanding and misinterpretation, both by news media and the public, and many of these have misunderstanding and fear of radiation at their heart. One problem is that it is extremely difficult to put a radiation-related hazard in proper perspective for the public without seeming either to exaggerate it or to minimize it. The best public reporting approach is to supply information as factually and objectively as possible--perhaps with the assistance of a technical expert who is recognized as an authoritative source.

Never tell a newsman something "off the record" which you are not prepared to see in print or hear on the air. A newsman's first responsibility is to his job. Also, competing newsmen will resent the exclusive information you have supplied to one individual and this will be damaging in your future relations.

As touched on above, newsmen will accept "classification" if it is honest. But don't use "classification" to conceal facts that newsmen can reasonably expect to be told. If they are not supplied basic facts, reporters--or their supervising editors--can be expected to speculate, sometimes quite erroneously. This creates problems.

Press briefings are valuable. They offer the opportunity for backgrounding, progress reports and dissemination of information on a timely and equal basis to a number of newsmen simultaneously. If possible, have experts (including a classification specialist) present to answer questions.

If newsmen request interviews, try to arrange them. Depending on the security sensitivity, it usually is wise to brief in advance the individuals who will be interviewed, to familiarize them with what should or should not be said.

Newsmen should be told where they can reach the public information officer at all times after the accident. After the first rash of public reporting, the information officer should learn deadlines of interested media, so he can keep newsmen advised of new developments on a timely basis.

To assist an emergency team in responding to requests for immediate information, some "canned" press releases have been prepared. This material is valuable when there is an immediate need to respond to press queries before all of the facts are known. It offers flexibility in replying.

The first of two releases, shown below, is for immediate use after incidents involving public safety.

ANNOUNCEMENT NO. 1 - (Format of releases to be used when confirmation of the presence of a nuclear weapon will have significant value in conjunction with public safety problems and as a means of reducing widespread public alarm, but no danger to the public from contamination or blast exists.)

A United States (type) aircraft (other vehicle) carrying (classified cargo), (an unarmed nuclear* weapon), accidently (crashed or other circumstances) approximately (location and time).

Against any remote danger (from the crash, or an atomic or high explosive

detonation*) however, in the interest of national security and to facilitate removal operations, visitors are asked to stay out of the area now under surveillance by guards, until the cargo has been removed. There is no need for evacuation.

ANNOUNCEMENT NO. 2 - (Format of release to be used if public safety considerations require announcement of fact that a nuclear device has been involved in an accident.)

An/a (aircraft) (railroad) (truck) (other) accident has occurred (state time and location) which involved conventional high explosives and radioactive materials.

There is no danger of an (atomic*) explosion. However, the conventional high explosives in the weapon (have detonated, are burning, may detonate). In the interest of public safety, visitors are asked to stay out of the area now under surveillance by guards (or indicate area). There is no need for evacuation. (If based on a competent assessment.)

An experienced explosive ordnance disposal team has been ordered to the scene of the accident as a precautionary measure (if true).

(If scattering of fissionable material is possible, the following may be added to the release.)

st potential danger in an accident of this kind is the effects of
d by detonation of the conventional high explosives in the weapon.
f nuclear material in the form of finely divided dust may
rom the explosion (fire). Such material would

be unfissioned, as opposed to fission fragments contained in fallout from weapons testing. It would have no significance to health unless taken into the body as by breathing or swallowing, and it is considered unlikely that any person would inhale or swallow an amount that would be hazardous to his health. (Spectators have been (are) warned to remain at least a half-mile--6 or 7 city blocks--from the accident scene (and if true) until a monitoring team, now enroute to the site of the accident, can survey the ground and verify the safety of adjacent areas.)

In summary, it should again be stressed that the DOE radiological emergency team members have no more police authority than any private citizen. For this reason the authority of local law enforcement agencies must be relied upon in dealing with citizens and private property. Team members should keep in mind that they are on official duty when sent out in response to requests for DOE assistance. Nevertheless, they as individuals are responsible for using good judgment in their actions. It should be borne in mind that the news media can be either a great help or a great hindrance at ar accident scene depending on the manner in which information is given and released by them. Therefore, it is the respor
team members to understand and follow the estab
for the public release of radiological accident

*Use the terms "weapon," "nuclear," "atomic,'
wording will not serve.

SECTION 31
GLOSSARY OF TERMS

ABSORBED DOSE

The absorbed dose of any ionizing radiation is the energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest. (See RAD).

ABSORPTION

The process by which the number of particles or quanta in a beam of radiation is reduced or degraded in energy as it passes through some medium. The absorbed radiation may be transformed into mass, other radiation, or energy by interaction with the electrons or nuclei of the atoms upon which it impinges. Often used when attenuation is meant; however, absorption refers specifically to processes by which radiation is transformed into mass or another form of energy.

ABSORPTION COEFFICIENT

Fractional decrease in the intensity of a beam of radiation per unit thickness (linear absorption coefficient), per unit mass (mass absorption coefficient), or per atom (atomic absorption coefficient) of absorber. For ordinary use in shielding problems, etc., the mass absorption coefficient is preferable. This is equal to the linear absorption coefficient divided by the density of the absorbing material and has units of cm^2/gram.

ACCELERATOR
A device for imparting a large amount of kinetic energy to charged particles, such as electrons, protons, deuterons, and helium ions. Common types of accelerators are the cyclotron, synchrotron, synchrocyclotron, betatron, linear accelerator, and Van de Graaf electrostatic generator.

ACID-PROOF

Impervious to chemical action by acids.

ACID-RESISTANT

Retards or prevents a particular action by an acid.

ACTIVATION ANALYSIS

A method of chemical analysis, especially for small traces of material, based on the detection of characteristic radionuclides following a nuclear bombardment.

ACTIVATION ENERGY

The energy necessary to cause a particular reaction to begin.

a. Nuclear: The amount of outside energy which must be added to a nucleus before a particular nuclear reaction will begin.

b. Chemical: The amount of outside energy necessary to activate an atom or molecule so as to cause it to react chemically.

ACTIVE MATERIAL

Fissionable material, such as plutonium-239, the isotope uranium-235, or the thorium-derived uranium isotope-233, which is capable of supporting a chain reaction. In the military field of atomic energy, the term refers to the nuclear components of atomic weapons exclusive of the natural uranium parts.

ACTIVITY

The rate of decay of radioactive material expressed as the number of nuclear disintegrations per second. (See CURIE).

ACUTE EXPOSURE

The term used to denote radiation exposure of short duration. Generally taken to be the total dose absorbed within 24 hours.

ACUTE TISSUE DAMAGE

Tissue damage resulting from a single exposure of short duration.

ADSORPTION

The surface adherance of one substance to another substance. Tritium is often adsorbed by zirconium accelerator targets.

ADVERSE EFFECTS

Unfavorable, harmful, or detrimental effects.

AIR DOSE

X-ray or gamma-ray dose expressed in roentgens delivered at a point in free air. In radiological practice it consists of the radiation of the primary beam and that scattered from surrounding air.

AIR WALL IONIZATION CHAMBER

Ionization chamber in which the materials of the wall and electrodes are so selected as to produce ionization essentially equivalent to that in a free air ionization chamber. This is possible only over limited ranges of photon energies. Such a chamber is more appropriately termed an air-equivalent ionization chamber.

ALPHA PARTICLE

A specific particle ejected spontaneously from the nuclei of some radioactive elements. It is identical to a helium nucleus which has an atomic mass number of 4 and an electrostatic charge of +2. It has low-penetrating power and short range. The most energetic alpha particle will generally fail to penetrate the skin. The danger occurs when matter containing alpha-emitting isotopes is introduced into the lungs or intestinal tract. The mass of the alpha particle is 4.00277 atomic mass units. Symbol: α.

ALIPHATIC

Organic compounds characterized by straight-chain arrangement of the carbon atoms.

ALVEOLI

The terminal air sacs of the lungs.

AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENIST (ACGIH)

A group organized in 1938, by Industrial Hygienist in government employment. The conference is not an official government agency. In 1977, membership in the organization exceeded 1600.

AMINO ACID

An organic acid; one of the building blocks in the formation of proteins.

AMPERE

Practical unit of current; the flow of 1 coulomb per second. Abbreviation: A.

AMPLIFICATION

As related to radiation-detection instruments, the process (either gas, electronic, or both) by which ionization effects are magnified to a degree suitable for their measurement.

ANEMIA

Deficiency of blood as a whole, deficiency in the number of red corpuscles, or of the hemoglobin.

ÅNGSTROM

A unit of length, used chiefly in expressing short wavelengths. It equals 10^{-10} meters or 10^{-8} centimeters. Symbol: Å.

ANION

Negatively charged ion.

ANNIHILATION RADIATION

Photons produced when an electron and a positron unite and cease to exist. The annihilation of a positron-electron pair results in the production of two photons, each of at least 0.51 MeV energy.

ANODE

Positive electrode: electrode to which negative ions are attracted.

ANOXIA

Oxygen deficiency: a condition which results from a diminished supply of oxygen to the tissues.

AROMATIC

Unsaturated cyclic hydrocarbons containing one or more rings, which are typified by the structure of benzene.

AS LOW AS PRACTICABLE (ALAP)

An DOE management commitment (DOE Manual Chapter 0524-012) stating in part that "operations shall be conducted in a manner to assure that radiation exposure to individuals and population groups is limited to the lowest levels technically and economically practicable."

ASSOCIATED CORPUSCULAR EMISSION

The full complement of secondary charged particles (usually limited to electrons) associated with an x-ray or gamma-ray beam in its passage through air. The full complement of electrons is obtained after the radiation has traversed sufficient air to bring about equillibrium between the primary photons and secondary electrons. Electronic equillibrium with the secondary photons is intentionally excluded.

ATMOSPHERIC ATTENUATION

Reduction in intensity of nuclear and thermal radiation due to absorption by the atmosphere.

ATMOSPHERIC TRANSMISSIVITY

The fraction of radiant energy received at some distance after passage through the atmosphere relative to that which would be received if the atmosphere were not present. In other words, it is a measure of the absorption of radiant energy in the air. The transmissivity is based upon the visibility (in miles) and the water vapor concentration in grams per cubic meter. Transmissivity may also refer to materials, such as glass, plastics, etc.

ATOM

The smallest particle of an element which cannot be divided or broken up by chemical means. It consists of a central core called the nucleus, which contains protons and neutrons. Electrons revolve in orbits in the region surrounding the nucleus.

ATOMIC ENERGY

Energy released in nuclear reactions. Of particular interest is the energy released when a neutron initiates the fissioning of an atom's nucleus into smaller pieces or when two nuclei are joined together under millions of degrees of heat (fusion). "Atomic energy" is really a popular misnomer. It is more correctly called "nuclear energy."

ATOMIC MASS

The weighted means of the masses of the neutral atoms of an element expressed in atomic weight units. Unless otherwise specified, it refers to a naturally occurring form of the element. The atomic weight of any element is the relative weight of its atom compared with the weight of one atom of carbon taken as 12; hence, a multiple of one-twelfth of the weight of a carbon atom.

ATOMIC MASS UNIT

Equals one-twelfth of the mass of one neutral ^{12}C atom. Abbreviation: amu. (See ATOMIC MASS).

ATOMIC NUMBER

The atomic number for any atom is the number of positive charges (protons) in its nucleus. It is also equal to the number of planetary electrons in an atom which is not in chemical combination with another. Symbol: Z.

ATROPHY

Wasting away or diminution in the size of cell, tissue, organ, or part from defect, failure of nutrition, or disuse.

AT UATION

The process by which primary quanta or particles are reduced in number on passing through some medium.

ATTENUATION FACTOR

The ratio of the incident intensity of radiation to the transmitted intensity.

AUTORADIOGRAPH

Record of radiation from radioactive material in an object, made by placing its surface in close proximity to a photographic emulsion.

AVOGADRO'S NUMBER

6.025×10^{23} atoms per gram--atomic weight or molecules per gram--molecular weight. Number of atoms in a gram-atomic weight of any element; also the number of molecules in the grammolecular weight of any substance. This is one of the fundamental physical constants.

AVALANCHE

The multiplicative process in which a single charged particle accelerated by a strong electric field produces additional charged particles through collision with neutral gas molecules. This cumulative increase of ions is also known as Townsend ionization or a Townsend avalanche.

AVERAGE LIFE (Mean-Life)

The average of the individual lives of all the atoms of a particular radioactive substance. It is 1.443 times the radioactive half-life.

BACKGROUND

The undesired radiation component detected by instruments due to cosmic rays, to radioactive materials in the vicinity, and to a slight radioactive contamination of the materials of which the instruments are made.

BACKGROUND RADIATION

Radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present. There also may be background radiation due to the presence of radioactive substances in other parts of the building, in the building material itself, etc.

BACKSCATTERING

The process of scattering or reflecting into the sensitive volume of a measuring instrument radioactive radiations originally having no positive component of motion in that direction. It is dependent, therefore, on the nature of the mounting material, the nature of the sample, the type and energy of the radiations, and the particular geometrical arrangement.

BACKSCATTERED RADIATION

Radiation normally proceeding in a direction so as not to be detected; that is, scattered or reflected into the detector from source backings (as in

accurate scaler countings) from the body (as on film badge), etc. The magnitude of the effect is dependent on the type and energy of the radiation, the geometrical arrangement, and the scattering material.

BARN

A unit of area for nuclear cross-section; used in expressing the probability of a specific nuclear reaction taking place. 1 b - 10^{-24} cm^2. Abbreviation: b. (See CROSS-SECTION)

BETA DECAY

Radioactive change by emission of a beta particle. In beta decay, a neutron decays into a proton with the emission of an electron or beta particle, or a proton transforms into a neutron and emits a positron. In both cases, the charge of the nucleus is changed without changing the number of nucleons.

BETA PARTICLE

A small particle ejected spontaneously from a nucleus of a radioactive element. It has the mass of the electron and has a charge of minus one (-1) or plus one (+1) and has a mass of 1/1840 that of a proton or neutron. It has a low-penetrating power and short range. The most energetic of beta particles will penetrate the skin and tissue. The damage is manifested by skin burns. Abbreviation: B^- or B^+.

BETA RAY

A stream of beta particles of nuclear origin more penetrating but less ionizing than alpha rays per unit length of travel; a stream of beta particles emitted in certain radioactive disintegrations.

BETATRON

A circular electron accelerator providing a pulsed beam of high-energy electrons or x-rays by magnetic induction.

BINARY SCALER

A scaler whose scaling factor is two per stage. (See SCALER).

BINDING ENERGY

The energy represented by the difference in mass between the sum of the component parts and the actual mass of the nucleus. It represents the amount of energy which would be required to separate the individual nucleons.

BIOLOGICAL DOSE

(See DOSE)

BIOLOGICAL HALF-LIFE

The time required for the body to eliminate one-half of an administered dose of any substance by regular processes of elimination. This time is approximately the same for both stable and radioactive isotopes of a particular element.

BLACK BODY

An ideal body which would absorb all (and reflect none) of the radiation falling upon it. The spectral energy distribution of a black body is described by Planck radiation equation. The total rate of emission of radiant energy is proportional to the fourth power of the absolute temperature (Stefan-Boltzmann law).

BLOOD DYSCRASIA

Any persistent change from normal of one or more of the blood components.

BODY BURDEN, MAXIMUM PERMISSIBLE

The amount of radioactive material in the critical organ so the whole-body dose is 0.3 rem per week or less; or in the case of an alpha or beta emitter that deposits in the bone, body burden is derived from the long-established, maximum permissible body burden of radium, 0.1μCi, adjusted for possible less uniform deposition. Abbreviation: q.

BONE MARROW

Soft material which fills the cavity in most bones; it manufactures most of the formed elements of the blood.

BONE SEEKER

Any compound or ion which migrates in the body preferentially to the bone.

BORON COUNTER TUBE

A counter tube filled with boron trifluoride (BF_3) and/or having electrodes coated with boron or boron compounds used for detecting slow neutrons by the (n, α) reaction of ^{10}B.

BREEDER

A reactor which is producing more atomic fuel than it is consuming. A nonfissionable isotope, bombarded by neutrons, is transformed into a fissionable material, such as plutonium, which can be used as fuel. Scientists are working toward the day when all the material burned in reactors will be replaced through this process. (See CONVERTER).

BREMSSTRAHLUNG

The production of electromagnetic radiation by the deceleration of a charged particle, usually an electron, while passing through matter. Examples are the continuous spectrum from an x-ray tube, and the electromagnetic radiation often noted from pure beta emitters, such as ^{32}P and ^{90}Sr.

BUILD-UP FACTOR

The ratio of the intensity of x-radiation or gamma radiation (both primary and scattered) at a point in an absorbing medium to the intensity of only the primary radiation. This factor has particular application for "broad beam" attenuation. "Intensity" may refer to energy flux, dose, or energy absorption.

CALIBRATION

Determination of variation from standard, or accuracy, of a measuring instrument, to ascertain necessary correction factors.

CALORIE (Gram-Calorie)

Amount of heat necessary to raise the temperature of 1 gram of water 1° C. (from 14.5° to 15.5° C.). Abbreviation: cal.

CANCER

Any malignant neoplasm. (Popular usage).

CAPILLARY

A small, thin-walled blood vessel connecting an artery with a vein.

CAPTURE CROSS-SECTION

The probability that a nucleus will capture an incident particle. The unit of cross-section is commonly the barn ($10^{-24}cm^2$).

CAPTURE, RADIATIVE

The process by which a nucleus captures an incident particle and loses its excitation energy immediately by the emission of gamma radiation.

CARCINOGENIC

Capable of producing cancer.

CARCINOMA

Malignant neoplasm composed of epithelial cells, regardless of their derivation.

CARRIER

a. A quantity of an element which may be mixed with radioactive isotopes of that element giving a ponderable quantity to facilitate chemical operations.

b. A substance in ponderable amount which, when associated with a trace of another substance, will carry the trace with it through a chemical or physical process, especially a precipitation process. If the added substance is a different element from the trace, the carrier is called a nonisotopic carrier.

CARRIER FREE

An adjective applied to one or more radioactive isotopes of an element in minute quantity, essentially undiluted with stable isotope carrier.

CATARACT

A clouding of the crystalline lens of the eye, which obstructs passage of light.

CATHODE

A negative electrode; an electrode to which positive ions are attracted.

CATION

A positively charged ion.

CELL (Biological)

The fundamental unit of structure and function in organisms.

CHAIN REACTION

Any chemical or nuclear process in which some of the products of the process have an effect on additional molecules of the reactants. (See NEUTRON CHAIN REACTION).

CHARACTERISTIC (Discrete) RADIATION

The essentially monochromatic radiation emitted by an atom when an orbital electron is removed or following excitation of the atom. Each element may emit a number of characteristic radiations, each of a constant wavelength and different from the characteristic radiations of all other elements.

CHARGE

The fuel (active material; also, fertile materials, such as ^{238}U, ^{232}Th) placed in a reactor to produce a chain reaction.

CHEMICAL COMPOUND

A substance composed of two or more elements combined in a fixed and definite proportion by weight.

CHEMICAL DOSIMETER

A self-indicating device for determining total (or accumulated) radiation exposure dose based on color changes accompanying chemical reactions induced by the radiation.

CHEMICAL (isotopic) EXCHANGE

A process in which atoms (isotopes) of the same element in two different molecules exchange places.

CHRONIC EXPOSURE

Term used to denote radiation exposure of long duration, by fractionation or protraction. Generally any dosage absorbed over a period of 24 hours or longer.

CHRONIC TISSUE DAMAGE

Tissue damage resulting from repeated long-term exposures.

CLAD

Of a metal, especially fuel, covered with a thin layer (cladding) of another metal; usually to prevent escape of fission products and to prevent corrosion.

CLINICAL

Pertaining to the observed symptoms and cause of disease.

CLOUD CHAMBER

A device for observing the paths of ionizing particles, based on the principle that supersaturated vapor condenses more readily on ions than on neutral molecules.

COINCIDENCE

The occurrence of ionizing events in one or more detectors simultaneously or within an assignable time interval, as a result of the passage of a single particle or of several generically related particles.

COINCIDENCE CORRECTION

A mathematical calculation to correct the observed count to the count free of coincidence losses.

COLLIMATION

Confining a beam of particles or rays to a defined cross-section.

COLLIMATOR

A device for confining the elements of a beam within an assigned solid angle.

COLLISION

The encounter between two subatomic particles (including photons) which changes the existing momentum and energy conditions. The products of the collision need not be the same as the initial systems.

COLLISION, ELASTIC

A billiard-ball-type collision in which energy and momentum are conserved and in which there is no change in the internal energy of the colliding objects.

COLLISION, INELASTIC

Collision in which at least one system gains internal excitation energy at the expense of the total kinetic energy of their center-of-gravity motion.

COLORIMETRY

An analytical technique based on measuring the color intensity of a substance or a colored derivative of it.

COMPOUND

Chemical combination of two or more elements combined in a fixed and definite proportion by weight.

COMPTON EFFECT

The interaction of a photon with matter wherein part of the photon energy is transferred to an orbital electron of an atom, the photon proceeding with altered direction and diminished energy. The electron is excited and ejected from the atom. The Compton effect is an important effect in the attenuation of x-rays or gamma rays, being especially effective for low- and intermediate-energy photons and for light-shielding materials.

COMPTON ELECTRON

An electron of increased energy ejected from an atom as the result of a Compton interaction with a photon. (See COMPTON EFFECT).

CONCENTRATION GUIDE (CG)

That amount of radioactive material which can be tolerated in the environment or in the body without the production of significant injury.

CONDENSER R-METER

An instrument consisting of an "air wall" ionization chamber together with auxiliary equipment for charging and measuring its voltage; it is used as an integrating instrument for measuring the quantity of x-radiation or gamma radiation in roentgens. (See IONIZATION CHAMBER).

CONTAMINATION

The deposition of radioactive material on the surfaces of structures, areas, objects, or personnel. This material can consist of fallout in which fission products and other nuclear debris have become incorporated with particles of dirt, etc. Contamination can also arise from the radioactivity induced in certain substances by the action of neutrons. (See DECONTAMINATION, FALLOUT, INDUCED RADIOACTIVITY, WEAPONS DEBRIS).

CONTROL ROD

A rod used to control the nuclear power of a nuclear reactor. The reactor functions through the fissioning of nuclear fuel by neutrons. The control rod absorbs neutrons which would normally fission atoms of the fuel. Pushing the rod in reduces the release of nuclear power. Pulling the rod out increases it. Another type of control rod operates with a rotary motion.

CONTROLLED AREA

A defined area in which the occupational exposure of personnel to radiation or radioactive material is under the supervision of an individual in charge of radiation protection.

CONVERTER

A nuclear reactor that converts fertile atoms into fuel by neutron capture. Two different ways of using the words "converter" and "breeder" are in use at present:

a. A converter is a reactor that uses one kind of a fuel and produces another; e.g., consumes ^{235}U and produces Pu from ^{238}U.

b. A breeder is a converter that produces more fissionable atoms than it consumes.

CORE

The heart of a nuclear reactor where the nuclei of the fuel fission (split) and release energy. The core is usually surrounded by a reflecting material which bounces stray neutrons back to the fuel.

CORPUSCLE

A blood cell.

COSMIC RADIATION

Penetrating ionizing radiation, both particulate and electromagnetic, originating in outer space. Secondary cosmic rays, formed by interactions in the earth's atmosphere, add to the general background radiation and contribute perhaps 1 rad or more to the gonads of each individual of the general population in 30 years.

COULOMB

Unit of electrical charge in the practical system of units. A quantity of electricity equal to 3×10^9 electrostatic units of charge.

COUNT (Radiation Measurements)

The external indication of a device designed to enumerate ionizing events. It may refer to a single detected event or to the total registered in a given period of time. The term often is erroneously used to designate a disintegration, ionizing event, or voltage pulse.

COUNTER

A device for counting nuclear disintegrations to measure radioactivity. The signal which announces a disintegration is called a count.

COUNT RATE METER

A device which gives a continuous indication of the average number of ionizing events detected. Most survey instruments have a count rate meter incorporated with a suitable detector.

COUNTING ERROR

Specifies the reliability of a measurement.

CRITICAL MASS

The minimum mass of a fissionable material that will just maintain a fission chain reaction under precisely specified conditions, such as the nature of the material and its purity, the nature and thickness of the tamper (or neutron reflector), the density (or compression), and the physical shape (or geometry). For an explosion to occur, the system must be supercritical; i.e., the mass of material must exceed the critical mass under the existing conditions. (See SUPERCRITICALITY). According to Graves and Paxton, the critical mass for a bare, isolated sphere of Oralloy (93.5% ^{235}U) is about 51 kg.

CRITICAL ORGAN

The body organ receiving the radionuclide that results in the greatest overall damage to the body. Usually, but not necessarily, it is the organ receiving the greatest concentration or the organ receiving the greatest damage.

CRITICAL SIZE

For a fissionable material, the minimum amount of material which will support a chain reaction.

CRITICALITY

A term used in weapon and reactor physics to describe the state of a given fission system when the specified conditions are such that the mass of active material present in the system is precisely a critical mass. Thus, the fission neutron production rate is a constant and is exactly balanced by the total of neutron loss and utilization rate, and the neutron population remains constant. See SUPERCRITICALITY. The word "criticality" alone is often used improperly to describe the degree of criticality of a system which is a relative term describing a variable physical property of the fissionable assembly. The degree of criticality is the ratio of the mass of active material actually present in the system to the critical mass (crit) under the identical conditions, and is usually expressed as a decimal.

CROSS-SECTION, NUCLEAR

The probability that a certain reaction between a nucleus and an incident particle of photon will occur. It is expressed as the effective "area" that the nucleus presents for the reaction. (See BARN).

CUMULATIVE DOSE (Radiation)

The total dose resulting from repeated exposures to radiation of the same region, or of the whole body.

CURIE

(Ci) Formerly defined as a quantity of any radioactive nuclide such that 3.7×10^{10} disintegrations occur per second. Now the curie is officially a unit of activity rather than quantity. The new definition is:
$1\ Ci = 3.7 \times 10^{10} s^{-1}$ or a unit of activity.

CYCLOTRON

A device for accelerating charged particles to high energies by means of an alternating electric field between electrodes placed in a constant magnetic field.

DAUGHTER PRODUCTS

Isotopes which are formed by the radioactive decay of some other isotope. In the case of radium-226, for example, there are 10 successive daughter products, ending in the stable isotope of lead-206.

DEAD TIME

The time during which a Geiger-Mueller detector is insensitive to incoming radiation.

DECADE SCALER

A scaler whose scaling factor is a power of 10. (See SCALER).

DECAY CONSTANT

The fraction of the number of radioisotope atoms which decay in unit time. Decay constant is 0.693/T, where T is the half-life.

DECAY CURVE

A curve showing the relative amount of radioactive substance remaining after any time interval.

DECAY PRODUCT

A nuclide resulting from the radioactive disintegration of a radionuclide or series of radionuclides. A decay product may be either stable or radioactive.

DECAY, RADIOACTIVE

The decrease in activity of any radioactive material with the passage of time, due to the spontaneous emission from the atomic nuclei of either alpha or beta particles, sometimes accompanied by gamma radiation. (See HALF-LIFE, RADIOACTIVE).

DECAY RATE

The decrease in the rate of emission of radioactive material with time. The decay rate of fission products is such that the dose rate in 7 hours will decrease to 1/10 of its H + 1 hour dose rate and to 1/100 of H + 1 hour dose rate at H + 14 hours. This is a convenient rule of thumb.

DECONTAMINATION

The reduction or removal of contaminating radioactive material from a structure, area, object, or person. Decontamination may be accomplished by (1) treating the surface to remove or decrease the contamination; (2) letting the material stand so that the radioactivity is decreased as a result of natural decay; and (3) covering the contamination to attenuate the radiation emitted. Radioactive material removed in process (1) above must be disposed of by burial on land or at sea, or in another suitable way.

DELINEATION

The outlining or marking of radioactively contaminated areas.

DENSITOMETER

An instrument utilizing the photoelectric principle to determine the degree of darkening of developed photographic film.

DENSITY (Photographic)

Logarithm of opacity of exposed and processed film. Opacity is the reciprocal of transmission. Transmission is the ratio of transmitted intensity to incident intensity. Density is used to denote the degree of darkening of photographic film.

DENSITY (Physical)

The weight of a substance per unit volume; e.g., gm/cm^3 or lb/ft^3.

DETAILED SURVEY

A survey to (1) find the radiation level of specific objects or locations within the contaminated area of interest; (2) locate regions of higher than average intensity; i.e., hot spots; and (3) establish with greater accuracy the position of the outer line of contamination and the danger line.

DEUTERON

The nucleus of a deuterium atom. Mass: about 2 amu (atomic mass unit). Abbreviation: d.

DIFFERENTIAL ABSORPTION RATIO

Ratio of concentration of an isotope in a given organ or tissue to the concentration that would be obtained if the same administered quantity of this isotope were uniformly distributed throughout the body.

DIRECT RADIATION

Obsolete term for radiation coming from within an x-ray tube and tube housing except the useful beam. Now designated as leakage radiation.

DISINTEGRATION

Process of spontaneous breakdown of a nucleus of an atom resulting in the emission of a particle and/or a photon. The rate of disintegration of a quantity of any radioactive nuclide is a function of the number of atoms present and a disintegration or decay constant characteristic of the nuclide concerned.

DISINTEGRATION CONSTANT

The fraction of the number of atoms of a radioactive isotope which decay in unit time; λ in the equation $N=N_0e^{-\lambda t}$, where N_0 is the initial number of atoms present, and N is the number of atoms present after some time, t. (See DECAY CONSTANT).

DISINTEGRATION, NUCLEAR

A spontaneous nuclear transformation (radioactivity) characterized by the emission of energy and mass from the nucleus. When numbers of nuclei are involved, the process is characterized by a definite half-life.

DOSE

A quantity (total or accumulated) of ionizing (or nuclear) radiation. The term "dose" is often used in the sense of the exposure dose, expressed in roentgens, which is a measure of the total amount of ionization that the quantity of radiation could produce in air. This should be distinguished from the absorbed dose, given in rep or rad, which represents the energy absorbed from the radiation per gram of specified body tissue. Further, the biological dose, in rem, is a measure of the biological effectiveness of the radiation exposure. (See RAD, RBE DOSE, REM, REP, ROENTGEN).

DOSE EQUIVALENT (or Dose Commitment)

The amount of radiation which may be received by an individual within a specified period with expectation of no harmful result. For long-continued x-ray or gamma-ray exposure of the whole body, the dose equivalent is 3 rem per quarter.

DOSE RATE

As a general rule, the amount of ionizing (or nuclear) radiation to which an individual would be exposed or which he would receive per unit of time. It is usually expressed as roentgens, rad, or rem per hour, or in multiples of submultiples of these units, such as milliroentgens per hour. The dose rate is commonly used to indicate the level of radioactivity in a contaminated area.

DOSIMETER

A portable instrument for measuring and registering the total accumulated exposure to ionizing radiations. (See DOSIMETRY).

DOSIMETRY

The theory and application of the principles and techniques involved in the measurement and recording of radiation doses. Its practical aspect is concerned with the use of various types of radiation instruments with which measurements are made. (See CHEMICAL DOSIMETER, FILM BADGE, SURVEY METER).

EDEMA

Presence of abnormally large amounts of fluid in the intercellular tissue spaces of the body or part of the body.

EFFECTIVE ATOMIC NUMBER

A number calculated from the composition and atomic numbers of a compound or mixture. An element of this atomic number would interact with photons in the same way as the compound or mixture.

EFFECTIVE HALF-LIFE

The time required for a radioactive element fixed in the tissues of an animal body to be diminished 50 percent as a result of the combined action of radioactive decay and biological elimination.

$$\text{Effective half life} = \frac{\text{Biological half-life x Radioactive half-life}}{\text{Biological half-life x Radioactive half-life}}$$

EFFICIENCY

A factor used to convert the counting rate of a detector to the disintegration rate of the radioactive material counted. Since usage and factors involved vary considerably with different detectors, it is well to ascertain which factors (window transmission, sensitive volume, energy dependence, etc.) are included in a stated efficiency.

ELECTRODE

Either terminal of an electrical apparatus.

ELECTROMAGNETIC RADIATION

A traveling wave motion resulting from changing electric or magnetic fields. Familiar electromagnetic radiations range from x-rays (and gamma rays) of short wavelength, through the ultraviolet, visible, and infrared regions, to radar and radio waves of relative long wavelength. All electromagnetic radiations travel in a vacuum with the velocity of light. (See PHOTON).

ELECTROMETER

Electrostatic instrument for measuring the difference in potential between two points. Used to measure a change of electric potential of charged electrodes resulting from ionization produced by radiation.

ELECTROMOTIVE FORCE

Potential difference across electrodes tending to produce an electric current. Abbreviation: emf.

ELECTRON

A negatively charged particle that is a fundamental constituent of all atoms. A unit of negative electricity equal to 4.802×10^{-10} esu. Its rest mass is 0.000548 amu and is approximately 1/1840 of the mass of the hydrogen atom. It is not found in the atomic nucleus but rather in orbits around the nucleus.

ELECTRON CAPTURE

adioactive decay in which an orbital electron merges with a
ie nucleus. Process is followed by emission of an electron
Capture from a particular electron shell is designated as
capture, L-electron capture, etc.

ELECTRON VOLT

A unit of energy equivalent to the amount of energy gained by an electron in passing through a potential difference of 1 volt. Larger multiple units of the electron volt are frequently used; viz: keV=thousand or kilo electron volts; MeV=million electron volts and BeV=billion electron volts. Equals 1.6×10^{-12} erg. Abbreviation: eV.

ELECTRONIC EQUILIBRIUM

The condition in which as many electrons are stopped as are produced in a slice of material when the material is under irradiation by photons.

ELECTROPHORESIS

Migration of suspended or colloidal particles in a liquid due to the effect of the potential (voltage) difference across electrodes immersed in the liquid.

ELECTROSCOPE

Instrument for detecting the presence of electric charges by the deflection of charged bodies.

ELECTROSTATIC FIELD

The region surrounding an electric charge in which another electric charge experiences a force.

ELECTROSTATIC PRECIPITATOR

A device which is usually used to remove charged particles from air flowing through it; high voltages are normally employed to create an electrostatic field or gradient across the collector.

ELECTROSTATIC UNIT OF CHARGE (Statcoulomb)

That quantity of electric charge which, when placed in a vacuum 1 centimeter distant from an equal and like charge, will repel it with a force of 1 dyne. Abbreviated: esu.

ELEMENT

A pure substance which cannot be broken down into a simpler substance by a chemical change or reaction, but which will disintegrate into simpler

particles by physical decomposition when they are exposed to drastic bombardments with high-energy particles.

ENERGY.

The capacity to do work. Energy (E) is the force (f) acting on a body to produce motion, multiplied by the distance (S) through which the force acts and the cosine of the angle (θ) between the direction of force and direction of motion. $E = fS \cos \theta$. Potential energy is energy due to relative position, for example, an elevated weight. Kinetic energy is energy due to motion, a speeding auto or electron. Energy is measured in ergs, joules, eV, MeV, etc.

ENERGY DEPENDENCE

The characteristic response of a radiation detector to a given energy is compared with some standard response. For γ survey instruments, radium or ^{60}Co is often used as standard.

ENZYME

An organic compound, frequently a protein, that accelerates (catalyzes) specific transformations of material as in the digestion of foods.

EPIDERMIS

The outermost layer of cells of the skin.

EPILATION (Depilation)

The temporary or permanent loss or removal of hair.

EPITHELIUM

A term applied to cells that line all canals and surfaces having communication with external air and also those that are specialized for secretion in certain glands as the liver, kidneys, etc.

ERG

The unit of work done by a force of 1 dyne acting through a distance of 1 centimeter. The unit of energy which can exert a force of 1 dyne through a distance of 1 centimeter. Centimeter-gram second (cgs) units: dyne-cm. or gm-cm^2/sec^2.

ERYTHEMA

An abnormal redness of the skin, due to distension of the capillaries with blood. It can be caused by many different agents; e.g., heat, certain drugs, ultraviolet rays, ionizing radiation.

EXCURSION

Pluctuations above or below a threshold limit value.

EXPOSURE

Contact of a body organ or tissue with a chemical substance, a living agent or a physical agent. The most important means of industrial chemical exposures to people are by inhalation, skin contact and ingestion.

EXPOSURE DOSE

A measure of the x-radiation or γ-radiation at a certain place based upon its ability to produce ionization. The unit is the roentgen (R).

EXPOSURE DOSE RATE

The exposure dose per unit time (R/unit time).

EXTERNAL RADIATION

Exposure to ionizing radiation when the radiation source is located outside the body and the radiation must then penetrate into the deeper tissues.

EXTRAPOLATION IONIZATION CHAMBER

An ionization chamber with electrodes whose spacing can be adjusted and accurately determined to permit extrapolation of its reading to zero chamber volume.

EXTREMITIES

The hands and forearms, and with restrictions, the head, feet, and ankles. (Permissible exposures in these regions are generally greater than whole body as they contain less blood-forming material and have smaller volumes for energy absorption than other body parts).

FALLOUT

Radioactive particulate matter dropping back to the earth's surface after having been sucked up or blown into the atmosphere by a nuclear detonation.

FALLOUT RADIATION

The portion of the total nuclear radiation associated with the deposition of radioactive particles from the weapon debris, etc. As such, it includes sources of fission products, gamma rays and beta rays, alpha particles from weapon debris, and induced gamma and beta activity from neutron interaction in nearby materials.

FILM BADGE

A pack of photographic film used for approximate measurement of radiation exposure for personnel monitoring purposes. The badge may contain two or three films of differing sensitivity, and it may contain a filter which shields part of the film from certain types of radiation.

FILM DOSIMETER

A pack of photographic film and appropriate filters used for the detection of ionizing radiation exposure to the individual wearing the dosimeter.

FIRST COLLISION DOSE

A term describing neutron dose. It involves the total energy imparted to charged particles for only the first collision of the neutron within the absorbing medium. It is not assumed that the energy of the secondary particles is completely liberated within the area of interest. Thus, the first collision dose may be smaller than the actual absorbed dose, depending on the radiation energy and the particles involved in the particular interaction.

FISSION

The process whereby the nucleus of a particular heavy element splits into two nuclei (generally) of lighter elements, with the release of substantial amounts of energy. The most important fissionable materials are uranium-235 and plutonium-239.

FISSION FRAGMENTS

The nuclei of elements produced by fission.

FISSION PRODUCTS

A general term for the complex mixture of substances produced as a result of nuclear fission. A distinction should be made between these and the direct fission products or fission fragments which are formed by the actual splitting of the heavy-element nuclei. Something like 80 different fission fragments result from roughly 40 different modes of fission of a given nuclear species; e.g., uranium-235 or plutonium-239. The fission fragments, being radioactive, immediately begin to decay, forming additional (daughter) products, with the result that the complex mixture of fission products so formed contains about 200 different isotopes of over 30 elements.

FLUORESCENCE

Phenomenon involving the absorption of radiant energy by a substance and its remission, only during the period of radiation excitation, as visible or near visible light.

FLUORESCENT SCREEN

A sheet of material coated with a substance, such as calcium tungstate or zinc sulfide, which will emit visible light when irradiated with ionizing radiation.

FLUORIMETRY

An analytical technique based on measuring the intensity of radiation of fluorescent compounds.

FLUOROGRAPHY (Photofluorography)

Photography of image produced on a fluorescent screen by x-radiation or gamma radiation.

FLUOROSCOPE

A fluoroscope screen suitably mounted with respect to an x-ray tube for ease of observation and protection, used for indirect visualization by means of x-rays of internal organs in the body or internal structures in apparatus or in masses of metal.

FLUX

A term applied to the number of light photons, gamma-ray photons, neutrons, particles, or energy, crossing a unit surface area per unit time. The units

of flux are a number of particles, energy, etc., per square centimeter per second.

FRACTIONATION

Any one of several processes, apart from radioactive decay, which result in change in the composition of the radioactive weapon debris. As a result of fractionation, the delayed fallout generally contains relatively more of strontium-90 and cesium-137 than does the early fallout from a surface burst.

FREE AIR IONIZATION CHAMBER

An ionization chamber in which a beam of radiation passes between the electrodes without striking them or other internal parts of the equipment. The electric field is maintained perpendicular to the electrodes in the collecting region; as a result, the ionized volume can be accurately determined from the dimensions of the collecting electrode and the limiting diaphragm. This is the basic standard instrument for x-ray dosimetry within the range of 5 to 400 kVp.

FREQUENCY

Number of cycles, revolutions, or vibrations completed per unit time.

FUEL ROD

A long, slender fuel assembly for nuclear reactor use.

FUME

Solid particles formed by condensation from the gaseous state, generally after volatilization of molten metals.

FUSION (Thermonuclear Reaction)

A nuclear reaction characterized by joining together of light nuclei to form heavier nuclei, the energy for the reactions being provided by kinetic energy derived from violent thermal agitation of particles at very high temperatures. If the colliding particles are properly chosen and the agitation is violent enough, there will be a release of energy from the reaction. The energy of the stars is believed to be derived from such reactions.

GAMMA RAYS (or Radiations)

Electromagnetic radiations of high energy originating in atomic nuclei and accompanying many nuclear reactions; e.g., fission, radioactivity, and neutron capture. Physically, gamma rays are identical with x-rays of high energy, the only essential difference being that the x-rays do not originate from atomic nuclei but are produced in other ways; e.g., by slowing down (fast) electrons of high energy. (See ELECTROMAGNETIC RADIATION).

GAS AMPLIFICATION

As applied to gas-ionization, radiation-detecting instruments, the ratio of the charge collected to the charge produced by the initial ionizing event.

GAS AMPLIFICATION FACTOR "A"

The number of electrons collected at the anode divided by the number of primary electrons formed.

GAS FLOW COUNTER (Radiation)

A counter in which an appropriate atmosphere is maintained in the counter tube by allowing a suitable gas to flow slowly through the sensitive volume.

GASES

Normally formless fluids which completely fill the space of enclosure and take the sahpe of their container; gases diffuse.

GEIGER REGION

In an ionization radiation detector, the operating voltage interval in which the charge collected per ionizing event is essentially independent of the number of primary ions produced in the initial ionizing event.

GEIGER THRESHOLD

Minimum voltage at which a Geiger-Mueller tube will indicate the presence of ionizing events.

GEIGER-MUELLER TUBE

A gas-filled chamber operated with a voltage such that a discharge triggered by a primary ionizing event will spread over the entire anode. Abbreviation: G-M tube.

GENE

The fundamental unit of inheritance which determines and controls hereditarily transmissible characteristics. Genes are arranged linearly at definite loci on chromosomes.

GONAD

A gamete-producing organ in animals; testis or ovary.

GRAM-ATOMIC WEIGHT

A mass in grams numerically equal to the atomic weight of an element.

GRAM-MOLECULAR WEIGHT (Gram-Mole)

Mass in grams numerically equal to the molecular weight of a substance.

GRENZ RAYS

X-rays produced at voltages of 5 to 20 kVp.

HALF-LIFE

The time required for the activity of a given radioactive element to decrease to half of its initial value due to radioactive decay. The half-life is a characteristic property of each radioactive element and is independent of its amount or condition. The effective half-life of a given isotope is the time in which the quantity in the body will decrease to half as a result of both radioactive decay and biological elimination. (See BIOLOGICAL HALF-LIFE).

HALF-LIFE, BIOLOGICAL

'ed for the body to eliminate half of the material taken
y natural biological means.

:FECTIVE

a radioactive isotope in a biologic organism resulting from
ı of radioactive decay and biologic elimination. It is related
ve half-life (T_r) and biological half-life (T_b) by the equation:

$$T = \frac{T_b \times T_r}{T_b + T_r}$$. Abbreviation: T.

HALF-LIFE, RADIOACTIVE

Time required for a radioactive substance to lose 50 percent of its activity by decay.

HALF-THICKNESS

The thickness of any given absorber that will reduce the intensity of a beam of radiation to one-half its initial value. It may be expressed in units of thickness or of mass-per-unit area.

HALF-VALUE LAYER (Half-Thickness)

The thickness of any particular material necessary to reduce the intensity of an x-ray or gamma-ray beam to one-half its original value.

HARDNESS

A relative specification of the quality or penetrating power of x-rays. In general, the shorter the wavelength, the harder the radiation.

HEALTH PHYSICS

A term in common use for that branch of radiological science dealing with the protection of personnel from harmful effects of ionizing radiation.

HEREDITY

Transmission of physical and psychical characters and traits from parent to offspring.

HOMOGENEOUS RADIATION

A beam or flux of radiation consisting of the same kind and energy.

HOT

A colloquial term meaning highly radioactive.

HOT SPOT

The region in a contaminated area in which the level of radiative contamination is somewhat greater than in neighboring regions in the area. (See CONTAMINATION).

IMPERMEABLE

A property of a material which does not permit the passage of a fluid (such as a liquid through it).

INDUCED RADIOACTIVITY

Radioactivity produced in certain materials as a result of nuclear reactions, particularly the capture of neutrons, which are accompanied by the formation of unstable (radioactive) nuclei. The activity induced by neutrons from a nuclear explosion in materials containing sodium, manganese, silicon, or aluminum may be significant.

INFRARED

Electromagnetic radiations of wavelength between the longest visible red (7000 Angstroms or 7×10^{-4} millimeters) and about 1 millimeter. (See ELECTROMAGNETIC RADIATION).

INHERENT FILTRATION (x-rays)

The filtration introduced by the wall of the x-ray tube and any permanent tube enclosure; to be distinguished from added primary and secondary filters

INITIAL NUCLEAR RADIATION

Nuclear radiation (essentially neutrons and gamma rays) emitted from the fire ball and the cloud column during the first minute after a nuclear explosion. The time limit of 1 minute is set, somewhat arbitrarily, as that required for the source of the radiations (fission products in the atomic cloud) to attain such a height that only insignificant amounts reach the earth's surface. (See RESIDUAL NUCLEAR RADIATION).

INTEGRAL ABSORBED DOSE

The energy imparted to matter by ionizing particles in a certain region of interest. The unit is the gram-rad and is equal to 100 ergs.

INTEGRATED DOSE (Volume Dose)

A measure of the total energy absorbed by a patient or any object during exposure to radiation. According to British usage, the integral dose of x-rays or gamma rays is expressed in gram-roentgens.

INTEGRATING CIRCUIT

The electronic circuit which records at any time an average value for the number of events occurring per unit time; or an electrical circuit which records the total number of ions collected in a given time.

INTEGRATING DOSE METER

The ionization chamber and measuring system designed for determining total radiation administered during an exposure. In medical radiology, the chamber is usually designed to be placed on the patient's skin. A device may be included to terminate the exposure when it has reached a desired value.

INTENSITY (Radiology)

The energy of any radiation incident upon (or flowing through) a unit area, perpendicular to the radiation beam, in unit time. As applied to nuclear radiation, the term "intensity" is sometimes used, rather loosely, to express the exposure dose rate at a given location; e.g., in roentgens (or milliroentgens) per hour.

INTERNAL CONVERSION

A mode of radioactive decay in which the gamma rays from excited nuclei cause the ejection of orbital electrons from the atom. The ratio of the number of internal conversion electrons to the number of gamma quanta emitted in the deexcitation of the nucleus is called the conversion ratio.

INTERNAL RADIATION

Nuclear radiation (alpha and beta particles and gamma radiation) resulting from radioactive substances in the body. Important sources are iodine-131 in the thyroid gland, and strontium-90 and plutonium-239 in the bone.

INVERSE SQUARE LAW

The law which states that when radiation (thermal or nuclear) from a point source is emitted uniformly in all directions, the amount received per unit area at any given distance from the source is inversely proportional to the square of that distance.

ION

The atomic particle, atom, or chemical radical (group of chemically combined atoms) bearing an electrical charge, either positive or negative, caused by an excess or deficiency of electrons.

ION EXCHANGE

A chemical process involving the reversible interchange of ions between a solution and a particular solid material, such as ion exchange resin consisting of a matrix of insoluble material interspersed with fixed ions of opposite charge.

ION PAIR

Two particles of opposite charge, usually referring to the electron and positive atomic or molecular residue resulting after the interaction of radiation with the orbital electrons of atoms.

IONIZATION

The separation of a normally electrically neutral atom or molecule into electrically charged components. The term is also employed to describe the degree or extent to which this separation occurs. Ionization is the removal of an electron (negative charge) from the atom or molecule, either directly or indirectly, leaving a positively charged ion. The separated electron and ion are referred to as an ion pair. (See IONIZING RADIATION).

IONIZATION CHAMBER

A device consisting of two oppositely charged plates used to measure radioactivity.

IONIZATION DENSITY

Number of ion pairs per unit volume.

IONIZATION PATH (Track)

The trail of ion pairs produced by an ionizing particle in its passage through matter.

IONIZATION POTENTIAL

The potential necessary to separate one electron from an atom, resulting in the formation of an ion pair.

Revised: January 1978

IONIZATION EVENT

An event in which an ion pair is produced.

IONIZING RADIATION

Electromagnetic radiation (x-ray or γ-ray photons or quanta) or corpuscular radiation (α particles, β particles, electrons, positrons, protons, neutrons, and heavy particles) capable of producing ions by direct or secondary processes. Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

IRRADIATION

Exposure to radiation.

IRREVERSIBLE TISSUE CHANGE

Changes which result in a lasting effect which may or may not be debilitating.

ISOBARS

Elements having the same mass number but different atomic numbers.

ISODOSE CHART

A chart showing the distribution of radiation in a medium by means of lines or surfaces drawn through points receiving equal doses. Isodose charts have been determined for beams of x-rays traversing the body, for radium applicators used for intracavitary or interstitial therapy, and for working areas where x-rays of radioactive isotopes are employed.

ISODOSE LINES

An unprecise term applied to imaginary lines on the ground (or on the water surface), or lines drawn on a map, joining points in a radioactive field at which the total accumulated radiation dosage is the same; sometimes used erroneously in place of the term "Isointensity lines".

ISOINTENSITY LINES

Imaginary lines on the ground (or in the water surface), or lines drawn on a map, joining points in a radioactive field which have the same radiation intensity at a given time. The lines are constructed on a map by adjusting,

to a common time, readings of radiation intensity, which have been taken at various points and different time, and then drawing lines.

ISOMER

One of several nuclides having the same number of neutrons and protons but capable of existing, for a measurable time, in different quantum states with different energies and radioactive properties. Commonly, the isomer of higher energy decays to one with lower energy by the process of isomeric transition.

ISOMERIC TRANSITION

The process by which a nuclide decays to an isomeric nuclide (i.e., one of the same mass number and atomic number) of lower quantum energy. Isomeric transitions, often abbreviated I.T., proceed by gamma ray and/or internal conversion electron emission.

ISOTOPE

One of several different nuclides having the same number of neutrons in their nuclei.

ISOTOPE EFFECT

The effect of the difference in the mass between isotopes of an element on the rate and/or equilibria of chemical transformations.

ISOTOPE SEPARATION

Process in which a mixture of isotopes of an element is separated into its component isotopes or in which the abundance of isotopes in such a mixture is changed.

ISOTOPES

Forms of the same element having identical chemical properties but differing in their atomic masses (due to different numbers of neutrons in their respective nuclei) and in their nuclear properties; e.g., radioactivity, fission, etc. For example, hydrogen has three isotopes, with masses of one, two, and three atomic mass units. ^{2}H and ^{3}H are commonly called deuterium and tritium respectively. The first two of these are stable (nonradioactive), but the third (tritium) is a radioactive isotope. Other examples are the common isotopes of uranium, with masses of 235 and 238 units, respectively, which

are radioactive, emitting alpha particles, but their half-lives are different. Further, uranium-235 is fissionable by neutrons of all energies, but uranium-238 will undergo fission only with neutrons of high energy.

K-ELECTRON CAPTURE

The process wherein an electron in the K-shell of an atom is captured by the nucleus during a nuclear reaction. In the process, a characteristic x-ray is emitted.

KEV (keV)

An abbreviation for kilo-electron-volt. The symbol for 1000 electron volts.

KILO-

Prefix indication for 1000, as in kilogram, kilocurie, or kilometer.

KILOVOLT

The unit of electrical potential equal to 1000 volts. Abbreviation: kV.

KILOVOLTS PEAK

The crest value of the potential wave in kilovolts. When only one-half of the wave is used, the crest value is to be measured on this half of the wave. Abbreviation: kVp.

KINETIC ENERGY

The energy which a body possesses by virtue of its mass and velocity, or the energy of motion. The equation for kinetic energy is: $K.E. = 1/2mv^2$, where m is a body of mass and v is velocity. (See ENERGY).

KINETIC ENERGY RELEASED IN MATERIAL (Kerma)

A term for the quantity which represents the kinetic energy transferred to charged particles by the uncharged particles per unit mass of the irradiated medium. This is the same as the "first collision dose" term used in neutron dosimetry.

LABELED COMPOUND

A compound consisting, in part, of labeled molecules. By observations of radioactivity or isotopic composition, this compound or its fragments may be followed through physical, chemical, or biological processes.

LABELED MOLECULE

A molecule containing one or more atoms distinguished by nonnatural isotopic composition (with radioactive or stable isotopes).

LATENT PERIOD

The period or state of seeming inactivity between the time of exposure of tissue to an injurious agent and the beginning of the response.

LD-50 or LD_{50}DOSE

The dose of radiation required to kill, within a specified period, 50 percent of the individuals in a large group of animals or organisms.

LESION

Any hurt, wound, or local degeneration.

LEUKEMIA

A disease in which there is great overproduction of white blood cells, or a relative overproduction of immature white cells, and great enlargement of the spleen. The disease is variable, at times running a more chronic course in adults than in children. It is almost always fatal. It can be produced in some animals by long, continued exposure to low intensities of ionizing radiation.

LINEAR ABSORPTION COEFFICIENT

A factor expressing the fraction of a beam of radiation absorbed in unit thickness of material. In the expression $I = I_0e_{-}\mu x$, I_0 is the initial intensity, I is the intensity after passage through a thickness of the material, μ (mu) is the linear absorption coefficient, and x is the distance traveled.

LINEAR ACCELERATOR

A device for accelerating particles employing alternate electrodes and gaps arranged in a straight line, so proportioned that when their potentials are varied in the proper amplitude and frequency, particles passing through them receive successive increments of energy.

Revised: January 1978

LINEAR AMPLIFIER

A pulse amplifier in which the output pulse height is proportional to an input pulse height for a given pulse shape up to a point at which the amplifier overloads.

LINEAR ENERGY TRANSFER

The linear rate of loss of energy (locally absorbed) by an ionizing particle traversing a material medium. It may be expressed in KeV/μ. Abbreviation: LET.

MALIGNANT TUMOR

A tumor capable of metastasizing.

MASS

The material equivalent of energy that is different from weight in that it neither increases nor decreases with gravitational force. It is one of the fundamental dimensions.

MASS ABSORPTION COEFFICIENT

The linear absorption coefficient in cm^{-1} divided by the density of the absorber in grams per cubic centimeter. It is frequently expressed as μ/p, where μ is the linear absorption coefficient and p is the absorber density.

MASS NUMBER

The number of nucleons (neutrons and protons) in the nucleus of an atom. Abbreviation: A.

MASS UNIT

A unit of mass based upon one-twelfth the weight of a carbon atom taken as 12.00000. Abbreviation: mu; or, atomic mass unit, amu.

MAXIMUM PERMISSIBLE DOSE (MPD)

For occupational exposures, MPD = 5 (N-18) where N is the age in years. Abbreviation: MPD.

MAXIMUM PERMISSIBLE EXPOSURE

The amount of radiation which may be received by an individual within a specified period without measurable residual injury. Abbreviation: MPE. Replaced by Radiation Protection Guide - (q.v.)

MEAN FREE PATH

The average distance a particle or photon travels between collisions.

MEAN LIFE

The reciprocal of the decay constant (λ). Abbreviation: χ.

MEDIAN LETHAL DOSE

The amount of radiation received over the whole body which would be fatal to about 50 percent of human beings, animals, or organisms. It is usually accepted that a dose of 400 to 450R (roentgens) received over the whole body in the course of a few minutes represents the median lethal dose for human beings. The term is sometimes abbreviated as MDL or LD-50.

MEGACURIE

One million curies. (See CURIE).

MESON

A short-lived particle, charged or uncharged, having a mass in multiples of the electron mass.

METABOLISM

The sum of all the physical and chemical processes by which living organized substance is produced and maintained and by which energy is made available for the uses of the organism.

METASTASIS

The transfer in the body of malignant neoplastic cells from the original or parent site to a more distant one.

METRIC TON

1000 kilograms; Equal to 2204.6 lbs. (avoirdupois); 2679.23 lbs. (troy)
Abbreviation: M.T.

MEV (or Million Electron Volt MEV)

A unit of energy commonly used in nuclear physics. It is equivalent to 1.6×10^{-6} erg. Approximately 200 MeV of energy are produced for every nucleus that undergoes fission. (See ELECTRON VOLT).

MICROCURIE

A one-millionth part of a curie. (See CURIE).

MICRON

A one-millionth part of a meter; i.e., 10^{-6} meter or 10^{-4} centimeter. It is roughly four one-hundred-thousandth (4×10^{-5}) of an inch.
Abbreviation: μ.

MICROSECOND

A one-millionth part of a second. Abbreviation: μ sec.

MILLIGRAMS PER CUBIC METER (mg/m^3)

Milligrams of a substance in one cubic meter of air.

MILLIREM

A one-thousandth part of a rem. (See REM).

MILLIROENTGEN

A one-thousandth part of a roentgen. Abbreviation: mR.

MODERATOR

A material used to slow down neutrons from the energies at which they are released to some lower energy (usually thermal energy, q.v.). Neutrons lose energy by scattering collisions with nuclei of the moderator. A good

moderator has a high-scattering cross-section and a large number of nuclei per unit volume (to increase collision probability), a low-capture cross-section (to reduce neutron losses), and a low atomic weight (to increase the energy transferred per collision). While no material has an ideal combination of nuclear and mechanical properties, hydrogen (water, plastics, paraffin), deuterium (heavy water), beryllium, and graphite have all found extensive use as moderators.

MOLECULAR WEIGHT

The relative weight of a molecule of any substance as compared to the weight of an atom of carbon (carbon has been accepted as the standard and assigned the value of 12.00000).

MOLECULE

Ultimate unit quantity of a chemical compound which can exist by itself and retain all the properties of the original substance.

MONITORING

Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an occupied region, as a safety measure, for purposes of health protection. Area Monitoring: Routine monitoring of the level of radiation or of radioactive contamination of any particular area, building, room, or equipment. Usage in some laboratories or operations distinguishes between routine monitoring and survey activities. Personnel Monitoring: Monitoring any part of an individual, his breath or excretions, or any part of his clothing. (See also RADIOLOGICAL SURVEY).

MONITORING SURVEY

Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination in an area, or on equipment or on personnel, as a safety measure for purposes of health protection.

MONOCHROMATIC RADIATION

Electromagnetic radiation of a single wavelength, or in which all the photons have the same energy.

MONOENERGETIC RADIATION

Particulate radiation of a given type (alpha, beta, neutron, etc.) in which all particles have the same energy.

MUTATION

A change in the characteristics of an organism produced by an alteration of the usual hereditary pattern.

MYLAR

A plastic material; as used in alpha survey instruments, a plastic coated with aluminum.

NAPHTHENIC

Derived from alicyclic hydrocarbons in which three or more of the carbon atoms in each molecule are united in a ring structure.

NEOPLASM

A new growth of cells which is more or less unrestrained and not governed by the usual limitations of normal growth. Benign: If there is some degree of growth restraint and no spread to distant parts. Malignant: If the growth invades the tissues of the host, spreads to distant parts, or both.

NEUTRON

A neutral particle (i.e., with no electrical charge) of approximately unit mass, present in all atomic nuclei, except those of ordinary (or light) hydrogen. Its rest mass is 1.00893 amu. Neutrons are used to initiate the fission process, and large numbers of neutrons are produced by both fission and fusion reactions in nuclear (or atomic) explosions.

NEUTRON CHAIN REACTION

A process in which some of the neutrons released in one fission event cause other fissions to occur. There are three types of chain reactions:

a. Nonsustaining Chain Reaction: An average of less than one fission is produced by the neutrons released by each previous fission.

b. Sustaining Chain Reaction: An average of exactly one fission is produced by the neutrons released by each previous fission.

c. Multiplying Chain Reaction: An average of more than one fission is produced by the neutrons released by previous fission.

NEUTRON FLUX

The product of the neutron density (number per cubic centimeter) multiplied by the velocity; the flux is expressed as neutrons per square centimeter per second. It is numerically equal to the total number of neutrons passing, in all directions, through a sphere of 1 square centimeter cross-sectional area per second.

NEUTRON-INDUCED GAMMA RADIATION

Gamma radiation incident to nuclear explosions generated by the interaction of neutrons with neutron-sensitive elements which, having absorbed (captured) a neutron, become radioactive and emit gamma radiation. Abbreviation: n, γ.

NUCLEAR DISINTEGRATION

A process resulting in the change of a radioactive nucleus through the emission of alpha or beta particles.

NUCLEAR FISSION

A special type of nuclear transformation characterized by the splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy when compared to that of a fusion reaction. Two or three neutrons are usually released during this type of transformation.

NUCLEAR FUSION

The joining (coalescence) of two or more nuclei.

NUCLEAR RADIATION

Particulate and electromagnetic radiation emitted from atomic nuclei in various nuclear processes. The important nuclear radiations, from the weapons standpoint, are alpha and beta particles, gamma rays, and neutrons. All nuclear radiations are ionizing radiations, but the reverse is not true; x-rays, for example, are included among ionizing radiations, but they are not nuclear radiations since they do not originate from atomic nuclei. (See IONIZING RADIATION).

NUCLEAR RADIATION SPECTRUM

The frequency distribution of nuclear or ionizing radiation with respect to energy. In this case it is well to remember that the gamma-ray spectrum

of the initial or the gamma and beta spectrum of the residual radiations may be approximated in the laboratory by high-energy x-ray or gamma-ray sources. Similarly the neutron spectrum may be approximated by laboratory sources, such as fission plates, the Godiva reactor, etc.

NUCLEAR REACTOR

An apparatus in which nuclear fission may be sustained in a self-supporting chain reaction. The usual components of a nuclear reactor are as follows:

a. Fissionable material (fuel), such as uranium or plutonium.

b. Moderating material (unless it is a fast reactor).

c. Usually a reflector to conserve escaping neutrons.

d. Provision for heat removal.

e. Measuring and controlling elements.

The terms "pile" and "reactor" have been used interchangeably.

NUCLEAR SYNTHESIS (Fusion)

The fusion of light nuclei to form more complex nuclei with an attendant release of energy resulting from a conversion of matter. An example is the reaction which occurs in the sun whereby helium is synthesized by the fusion of hydrogen atoms with an overall reduction of mass that results in an equivalent release of energy.

NUCLEAR WEAPON

A general name given to any weapon in which the explosion results from the energy released by reactions involving atomic nuclei, either fission or fusion, or both. Thus, the A- (or atomic) bomb and the H- (or hydrogen) bomb are both nuclear weapons. It would be equally true to call them atomic weapons, since it is the energy of atomic nuclei that is involved in each case. However, it has become more or less customary, although it is not strictly accurate, to refer to weapons in which all the energy results from fission as A-bombs or atomic bombs. In order to make a distinction, those weapons in which part, at least, of the energy results from thermonuclear (fusion) reactions among the isotopes of hydrogen have been called H-bombs or hydrogen bombs.

NUCLEON

Common name for a constituent particle of the nucleus. At present, applied to protons and neutrons but will include any other particle found to exist in the nucleus.

NUCLEON NUMBER

Total number of neutrons and protons in the nucleus. Also called the mass number.

NUCLEUS (or Atomic Nucleus)

The small, central, positively charged region of an atom which carries essentially all the mass. Except for the nucleus of ordinary (light) hydrogen, which is a single proton, all atomic nuclei contain both protons and neutrons. The number of protons determines the total positive charge, or atomic number; this is the same for all the atomic nuclei of a given chemical element. The total number of neutrons and protons, called the mass number, is closely related to the mass (or weight) of the atom. The nuclei of isotopes of a given element contain the same number of photons, but different numbers of neutrons. They thus have the same atomic number, and so are the same element, but they have different mass numbers.

NUCLIDE

A general term referring to any nuclear species, both stable (about 270) and unstable (about 5000), of the chemical elements.

N-UNIT

The quantity of neutron radiation measured in a Victoreen Condenser R-meter that will produce the same amount of ionization as one roentgen of x-radiation.

OCCUPATIONAL ILLNESS

An illness derived from and arising out of the workplace; caused by some exposure in the work environment.

OLEFINIC

A class of unsaturated aliphatic hydrocarbons.

OPERATING VOLTAGE

As applied to radiation-detection instruments, the voltage across the electrodes in the detecting chamber is required for proper detection of an ionizing event.

ORALLOY

Uranium enriched in the isotope ^{235}U. This material is an excellent fission fuel and is capable of sustaining a chain reaction. Abbreviation: Oy.

ORGAN

Organized group of tissues having one or more definite functions to perform in an animal body.

OSMOSIS

The diffusion which proceeds through a semipermeable membrane separating two miscible solutions and tends to equalize their concentrations.

OSMOTIC

Pertaining to osmosis.

PAIR PRODUCTION

The process whereby a gamma-ray (or x-ray) photon, with energy in excess of 1.02 MeV, in passing near the nucleus of an atom is converted into a positive electron and a negative electron. As a result, the photon ceases to exist. (See PHOTON).

PARTICULATE MATTER

Normally refers to dusts and fume.

PARTS PER MILLION (ppm)

Parts of a substance contained in a million parts of air by volume.

PERCENTAGE DEPTH DOSE

Amount of radiation delivered at a specified depth in tissue, expressed as a percentage of the amount delivered at the skin.

PERIODIC TABLE

An arrangement of chemical elements in order of increasing atomic number. Elements of similar properties are placed one under the other, yielding

groups and families of elements. Within each group there is a gradation of chemical and physical properties but in general a similarity of chemical behavior. From group to group, however, there is a progressive shift of chemical behavior from one end of the table to the other.

PERMEABLE

Affording passage or penetration.

PERSONNEL DECONTAMINATION

The removal of radioactive material from skin, hair, or clothing by appropriate mechanical and/or chemical means.

PERSONNEL DECONTAMINATION CENTER

The space in a building or area in which an individual who has been exposed to radioactive contamination may (1) remove his clothing and have his person monitored for radioactivity, (2) remove radioactivity from his person by bathing and/or chemical procedures, and (3) have issued to him clean clothing and dosimetry devices before starting work.

PERSONNEL MONITORING

The determination of the degree of radioactive contamination on individuals, using standard survey meters, and the determination of dosage received by means of dosimetry devices.

PHOSPHOR

A material which has the ability to absorb energy from incident radiation and emit a portion of this energy as visible or ultraviolet light.

PHOSPHORESCENCE

The emission of radiation by a substance as a result of previous absorption of radiation of shorter wavelength. In contrast to fluorescence, the emission may continue for a considerable time after cessation of the exciting irradiation.

PHOTODOSIMETRY

The determination of the cumulative dose of ionizing radiation by use of photographic film.

PHOTOELECTRIC EFFECT

A process by which a photon ejects an electron from an atom. All the energy of the photon is absorbed in ejecting the electron and in imparting kinetic energy to it. This effect as an absorption process is large for low-energy photons impinging on high Z-elements.

PHOTOGRAPHIC DOSIMETRY

The determination of the cumulative dose of ionizing radiation by use of photographic film.

PHOTON

A quantum of energy emitted or absorbed in the form of electromagnetic radiation whose energy value is the product of its frequency and Planck's constant. $E = h\nu$.

PHOTONEUTRON

A neutron released from a nucleus in a photonuclear reaction.

PHOTONEUTRON SOURCE

A source of neutrons in which the nuclear reaction is induced by a γ-ray or x-ray impinging on a light element, such as beryllium or deuterium.

PIG

A container (usually lead) used to ship or store radioactive materials. The thick walls protect the person handling the container from radiation.

PILE

A nuclear reactor. Called a pile because the earliest reactors were "piles" of graphite blocks and uranium slugs.

PLANCK'S CONSTANT

A natural constant of proportionality (h) relating the frequency of a quantum of energy to the total energy of the quantum:

$$h = \frac{E}{\nu} = 6.6 \times 10^{-27} \text{ erg-sec.}$$

PLATEAU

As applied to radiation detector chambers, the level portion of the counting rate-voltage curve where changes in operating voltage introduce minimum changes in the counting rate.

PNEUMONITIS

Characterized by inflamation of the lungs.

POCKET CHAMBER

A small condenser ionization chamber used for determining radiation exposure. An auxilliary charging and reading device is usually necessary.

POCKET DOSIMETER

A small ionization instrument which indicates radiation exposure directly. An auxilliary charging device is usually necessary.

POLYCYTHEMIA

A disease characterized by overproduction of red blood cells (erythrocytes).

POSITRON

Particle equal in mass, but opposite in charge, to the electron, q.v. A positive electron.

POTENTIAL DIFFERENCE

Work required to carry a unit positive charge from one point to another.

PRIMARY ELECTRON

The electron ejected from an atom by an initial ionizing event, as caused by a photon or beta particle.

PRIMARY IRRITATION

Irritation cuased by direct action at the site of contact.

PRIMARY PROTECTIVE BARRIERS

Barriers sufficient to reduce the useful beam to the permissible dose rate.

PRIMARY RADIATION

Radiation arising directly from the target of an x-ray tube or from a radioactive source.

PROBABILITY

The ratio of the number of outcomes favorable to the total number of possible outcomes for an event.

PROMPT GAMMA

Gamma radiation emitted at the time of fission of a nucleus.

PROMPT NEUTRONS

Neutrons emitted during the fission process.

PROPORTIONAL COUNTER

An instrument in which a gas-filled radiation detection tube or chamber receives pulses which are proportional to the number of ions formed in the gas by the primary ionizing particles.

PROPORTIONAL REGION

The voltage range in which the gas amplification is greater than one and in which the charge collected is proportional to the charge produced by the initial ionizing event.

PROTECTIVE BARRIERS

Barriers of radiation-absorbing material, such as lead, concrete, and plaster, that are used to reduce radiation hazards.

PROTON

An elementary nuclear particle with a positive electric charge equal numerically to the charge of the electron and having a rest mass of 1.007575 atomic mass units.

PULMONARY EDEMA

An abnormal collection of fluid in the lungs.

PULSE HEIGHT SELECTOR

A circuit designed to select and pass voltage pulses in a certain range of amplitudes.

PURPURA

Large hemorrhagic spots in or under the skin or mucous tissues.

QUALITY (Radiology)

The characteristic spectral energy distribution of x-radiation. It is usually expressed in terms of effective wavelengths or half-value layers of a suitable material; viz, up to 20 kV. (peak), cellophane; 20 to 120 kV. (peak) aluminum; 120 to 400 kV. (peak), copper; and over 400 kV., tin.

QUALITY FACTOR (QF)

The linear-energy-transfer-dependant factor by which absorbed doses are multiplied to obtain (for radiation purposes) a quantity that expresses--on a common scale for all ionizing radiations--the effectiveness of the absorbed dose.

QUANTUM

The smallest quantity of energy constituting a photon of electromagnetic radiation which can be associated with a given phenomenon.

QUANTUM THEORY

The concept that energy is radiated intermittently in units of definite magnitude called quanta, and absorbed in a like manner.

QUENCHING

The process of inhibiting continuous or multiple discharge in a counter tube which uses gas amplification.

QUENCHING VAPOR

Polyatomic gas used in Geiger-Mueller counters to quench or extinguish avalanche ionization.

RAD

An acronym for Radiation Absorbed Dose. The unit of absorbed dose, which is 100 ergs/gm. The rad is a measure of the energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest. It is a unit that was recommended and adopted by the International Commission on Radiological Units at the Seventh International Congress of Radiology, Copenhagen, in July of 1963.

RADIAC

An acronym, from "radioactivity detection indication and computation," a generic term applying to the various types of radiological instruments or equipment, normally used as an adjective modifying "instruments," but also used as a noun to designate the equipment itself.

RADIANT ENERGY

The energy of electromagnetic waves, such as radio waves, visible light, x-rays, and gamma rays.

RADIATION

a. The emission and propagation of energy through space or through a material medium in the form of waves; for instance, the emission and propagation of electromagnetic waves, or of sound and elastic waves.

b. The energy propagated through space or through a material medium as waves; for example, energy in the form of electromagnetic waves or of elastic waves. The term "radiation," or radiant energy, when unqualified, usually refers to electromagnetic radiation; such radiation commonly is classified, according to frequency, as Hertzian, infrared, visible (light), ultraviolet, x-ray, and gamma ray. (See PHOTON).

c. By extension, corpuscular emissions, such as alpha and beta radiation, or rays of mixed or unknown type, as cosmic radiation.

RADIATION HAZARD

A condition under which persons might receive radiation in excess of the applicable maximum permissible dose, or where radiation damage might be caused to materials.

RADIATION PROTECTION STANDARDS

The total amount of ionizing radiation dose over certain periods of time which may be permitted to persons whose occupation involves exposure to such radiation.

RADIATION SICKNESS (Radiation therapy)

A self-limited syndrome characterized by nausea, vomiting, diarrhea, and psychic depression, following exposure to appreciable doses of ionizing radiation, particularly to the abdominal region. Its mechanism is unknown, and there is no satisfactory remedy. It usually comes on a few hours after a treatment and may subside within a day. It may be sufficiently severe to necessitate interrupting the treatment series, or to incapacitate the patient.

RADIATION SYNDROME

(See SYNDROME).

RADIOACTIVE EQUILIBRIUM

Among the members of a radioactive series, the state which prevails when the ratios between the amounts of successive members of the series remain constant. Secular equilibrium: If a parent element has a very much longer half-life than the succeeding ones, so that there is no appreciable change in its amount in the time interval required for the later products to attain equilibrium, then, after the condition is reached, equal numbers of atoms of all members of the series disintegrate in unit time. This condition is never actually attained but is essentially established in such a case as radium and its series through Radium C. The half-life of radium is 1600 years; of radon, 3.82 days; and of each of the subsequent members, a few minutes. After about a month, essentially the equilibrium amount of radon is present; and then for a long time, all members of the series through Radium C.

RADIOACTIVE (or Atomic) CLOUD

An all-inclusive term for the mixture of hot gases, smoke, dust, and other particulate matter from the weapon itself and from the environment, which is carried aloft in conjunction with the rising fireball produced by the detonation of a nuclear (or atomic) weapon.

RADIOACTIVITY

The spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nucleus of an (unstable) isotope.

As a result of this emission, the radioactive isotope is converted (or decays) into the isotope of a different element which also may (or may not) be radioactive. Ultimately, as a result of one or more stages of radioactive decay, a stable (nonradioactive) end product is formed.

RADIOBIOLOGY

That branch of biology which deals with the effects of radiation on biological systems.

RADIOGRAPHY

The making of shadow images on photographic emulsion by the action of ionizing radiation. The image is the result of the differential absorption of the radiation in its passage through the object being radiographed.

RADIOLOGICAL HEALTH

The art and science of protecting human beings from injury by radiation.

RADIOLOGICAL SURVEY

The evaluation of the radiation hazards incident to the production, use, or existence of radioactive materials or other sources of radiation under a specific set of conditions. Such evaluation customarily includes a physical survey of the disposition of materials and equipment, measurements or estimates of the levels of radiation that may be involved, and a sufficient knowledge of processes using or affecting these materials to predict hazards resulting from expected or possible changes in materials or equipment.

RADIOLOGY

That branch of medicine which deals with the diagnostic and therapeutic applications of radiant energy including x-rays and radioisotopes.

RADIOSENSITIVITY

The relative susceptibility of cells, tissues, organs, organisms, or any substances to the injurious action of radiation. Radioresistance and radiosusceptibility are at present employed in a comparative sense, rather than in an absolute one.

RANGE (Radiation)

The distance radiation will penetrate a given material before all of its ionizing power is spent.

RBE

An abbreviation for Relative Biological Effectiveness. The ratio of the number of rad of gamma radiation or x-radiation of a certain energy which will produce a specified biological effect to the number of rad of another radiation required to produce the same effect is the RBE of this latter radiation.

RBE DOSE

The product of the absorbed dose in rad and an agreed conventional value of RBE with respect to a particular form of radiation effect. The standard of comparison recommended by the International Commission on Radiological Units and Measurements (ICRU) is x-radiation or γ-radiation with a LET in water of 3 KeV/μ delivered at a rate of about 10 rad per minute. The unit of RBE dose is the rem. The RBE dose equals rad times RBE.

REACTION

Any process involving a chemical or nuclear change.

REACTOR, NUCLEAR

A device in which nuclear fission may be sustained and controlled in a self-supporting nuclear reaction. The varieties are many, but all incorporate certain features including fissionable material or fuel, a moderating material (unless the reactor is operated on fast neutrons), a reflector to conserve escaping neutrons, and a provision for removal of heat, for measuring and controlling elements, and for personnel protection.

RECOVERY (Radiobiology)

The return toward normal of a particular cell tissue, or organism, after radiation injury.

RECOVERY RATE

The rate at which recovery takes place following radiation injury. It may proceed at different rates for different tissues. Differential

recovery rate: Among tissues recovering at different rates, those having slower rates will ultimately suffer greater damage from a series of successive irradiations. This differential effect is taken advantage of in fractionated radiation therapy if the neoplastic tissues have a slower recovery rate than the surrounding normal structures.

REGENERATIVE PROCESS

The process by which damaged cells are replaced by new ones of the same type.

RELATIVE BIOLOGICAL EFFECTIVENESS (RBE)

The RBE is a factor used to compare the biological effectiveness of absorbed doses (i.e., rads) due to different types of radiation. More specifically, it is the experimentally determined ratio of an absorbed dose of a radiation in question to the absorbed dose of a reference radiation required to produce an identical biological effect in a particular experimental organism or tissue. Note: This term should not be used in radiation protection. (See QUALITY FACTOR.)

RELATIVE PLATEAU SLOPE

The relative increase in the number of counts as a function of voltage expressed in percentage per 100-volt increase above the Geiger threshold.

RELATIVISTIC MASS

The increased mass associated with a particle when its velocity is increased. The increase in mass becomes appreciable only at velocities approaching the velocity of light, 3×10^{10} cm./sec.

REM

An abbreviation for the term "Roentgen Equivalent Man (or Mammal)". A unit of biological dose of radiation where the number of rem of radiation is equal to the number of rad absorbed multiplied by the RBE of the given radiation (for a specified effect). (See RAD, RBE DOSE.)

REP

An abbreviation for the obsolete term "Roentgen Equivalent Physical." A unit of absorbed dose of radiation. Basically, the rep is intended to express absorption of gamma radiation or x-radiation. This is estimated

to be about 97 ergs per gram of tissue although the actual value depends on certain experimental data which are not precisely known. The rep is thus defined, in general, as the dose of any ionizing radiation which results in the absorption of about 97 ergs of energy per gram of soft tissue. For soft tissue, the rep and the rad are essentially the same. (See RAD, ROENTGEN.)

RESIDUAL NUCLEAR RADIATION

Nuclear radiation, chiefly beta particles and gamma rays, which persists for some time following a nuclear explosion. The radiation is emitted mainly by the fission products and other bomb residues in the fallout, and to some extent by earth and other materials, in which radioactivity has been induced by the capture of neutrons. (See FALLOUT, INDUCED RADIOACTIVITY, INITIAL NUCLEAR RADIATION.)

RESIDUAL NUMBER

A measure of the effectiveness of a countermeasure or a measure of the effectiveness of a reclamation method. Abbreviation: RN.

RESOLVING TIME, COUNTER

The minimum time interval between two distinct events which will permit both to be counted. It may refer to an electronic circuit, to a mechanical indicating device, or to a counter tube.

RESONANCE CAPTURE

An inelastic nuclear collision occurring when the nucleus exhibits a strong tendency to capture incident particles, photons, of particular energies.

RESPIRATION (Biological)

The taking in of oxygen and giving off of carbon dioxide, and all steps involved in the process.

RESPIRATORY SYSTEM

The group of organs concerned with the exchange of oxygen and carbon dioxide in organisms. In higher animals these consist successively of the air passages through the mouth, nose, and throat; the trachea; the bronchi; the bronchioles; and the alveoli of the lungs.

Revised: January 1978

ROENTGEN

A unit of exposure dose of gamma radiation or x-radiation. It is defined precisely as the quantity of gamma radiation or x-radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit quantity of electricity of either sign. From the accepted value for the energy lost by an electron in producing a positive-negative ion pair in air, it is estimated that 1 roentgen of gamma radiation or x-radiation would result in the absorption of about 87 ergs of energy per gram of air. Abbreviation: R.

ROENTGEN EQUIVALENT MAN (or Mammal)

The quantity of ionizing radiation of any type which, when absorbed by man or other mammal, produces a physiological effect equivalent to that produced by the absorption of 1 roentgen of x-rays or gamma rays. Abbreviation: REM.

ROENTGEN EQUIVALENT PHYSICAL

An obsolete unit of absorbed dose of ionizing radiation equal to 97 ergs per gram of tissue. Cf. Roentgen Equivalent Man (or Mammal). Abbreviation: rep.

SARCOMA

Malignant neoplasm composed of cells imitating the appearance of the supportive and lymphatic tissues.

SCALER

An electronic device that produces an output pulse whenever a prescribed number of input pulses have been received.

SCALING LAWS

The methods by which weapons effects may be estimated for varying yields. For blast, it has been found that such things as overpressure, time of arrival, etc., scale as the cube root of the yield ($W^{1/3}$). For thermal effects, it is found that the total thermal energy is directly proportional to the weapon's yield (W^1). Similar approximations may be made for initial nuclear radiation estimates. However, all scaling laws must be modified depending upon the conditions of the burst. These include height of burst, the yields themselves when widely divergent yields are compared, and the weapon design itself.

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SCATTERED RADIATION

Radiation which, during its passage through a substance, has been deviated in direction. It may also have been modified by an increase in wavelength. It is one form of secondary radiation.

SCATTERING

The diversion of radiation, either thermal or nuclear, from its original path as a result of interactions (or collisions) with atoms, molecules, larger particles in the atmosphere, or other medium between the source of the radiations; e.g., a nuclear (or atomic) explosion, and a point at some distance away. As a result of scattering, radiations (especially gamma rays and neutrons) will be received at this point from many directions instead of only from the direction of the source.

SCINTILLATION COUNTER

The combination of a phosphor (converts ionizing particle energy to a light pulse), a photomultiplier (converts a light pulse to many electric pulses), and associated circuitry for counting the electric pulses.

SCINTILLATION DETECTOR

The combination of phosphor, photomultiplier tube, and associated electronic circuits for counting light emissions produced in the phosphor by ionizing radiation.

SCRAM

Sudden shutting down of a nuclear reactor, usually by dropping of safety rods.

SEALED SOURCE

Radioactive material that is encased in, and is to be used in, a container in a manner intended to prevent leakage of the radioactive material.

SECONDARY RADIATION

Radiation originating as the result of absorption of other radiation in matter. It may be either electromagnetic or particulate in nature.

SELECTIVE LOCALIZATION (Biology)

As applied to radioisotopes, the accumulation of a particular isotope to a significantly greater degree in certain cells or tissues. (See DIFFERENTIAL ABSORPTION RATIO).

SELF CONTAINED BREATHING APPARATUS (SCBA)

A breathing apparatus which is attached to a portable source of air or oxygen which is worn by the user.

SELF-ABSORPTION

Absorption of radiation emitted by radioactive atoms by the matter in which the atoms are located; in particular, the absorption of radiation within a sample being assayed.

SENSITIVE VOLUME

The portion of a counter tube or ionization chamber that responds to a specific radiation.

SHIELDING

Any material or obstruction which absorbs radiation and thus tends to protect personnel or materials from the effects of nuclear radiation. A moderately thick layer of any opaque material will provide satisfactory shielding from thermal radiation, but a considerable thickness of material of high density may be needed for nuclear radiation shielding.

SIGMOID CURVE

S-shaped curve, often characteristic of a dose-effect curve in radiobiological studies.

SKIN DOSE (Radiology)

Dose at center of irradiation field on skin. It is the sum of the air dose and back scatter.

SKYSHINE

Radiation, particularly gamma rays from a nuclear explosion, reaching a target from many directions as a result of scattering by the oxygen and nitrogen in the intervening atmosphere.

SLUG

A bar-shaped piece of material prepared especially for insertion in a nuclear reactor. The term often refers to the fuel unit of a natural uranium-graphite reactor.

SLURRY CONTAMINANT

A mixture of small particles of earth in water, a product of the nuclear detonation containing radioactivity.

SPECTROGRAPHIC

An analytic technique based on measuring the intensity of emissions radiated from an excited atom.

SOFTNESS

A relative specification of the quality or penetrating power of x-rays. In general, the longer the wavelength, the softer the radiation.

SOMATIC CELLS

Body cells, usually having two sets of chromosomes, as opposed to germ cells.

SOURCE

Discrete amount of radioactive material or radiation producing equipment.

SPECIFIC ACTIVITY

The total radioactivity of a given isotope per gram, given in Ci/g or d/s-g.

SPECIFIC ACTIVITY, COMPOUND

Total radioactivity of a given isotope per gram of compound.

SPECIFIC ACTIVITY, ISOTOPE

Total radioactivity of a given isotope per gram of the radioactive isotope.

SPECIFIC IONIZATION

Number of ion pairs per unit length of path of the ionizing particle in a medium; e.g., per centimeter of air or per micron of tissue.

SPECTRAL DISTRIBUTION

The distribution of energy throughout the electromagnetic spectrum. For thermal effects on people, one considers the spectrum from weapons to be quite similar to that from the sun.

SPURIOUS COUNT

In a radiation-counting device, a count caused by any agency other than radiation.

STABLE ISOTOPE

A nonradioactive isotope of an element.

STAY TIME

The period during which personnel are allowed to remain in a radiation and/or contaminated area before accumulating their permissible dose.

STEM RADIATION

X-rays given off from parts of the anode other than the target; in particular, from the target support.

STERILITY (Biological)

The temporary or permanent incapability to reproduce.

STOPPING POWER

The reciprocal of the thickness of a solid that absorbs the same amount of alpha radiation as 1 centimeter of air.

STRAY RADIATION

Radiation not serving any useful purpose. It includes direct radiation and secondary radiation from irradiated objects.

SUPERCRITICALITY

A term used to describe the state of a given fission system when the specified conditions are such that a greater than critical mass of active material is present. Thus, this is the condition for increasing the level of operation of a reactor or for the explosion of a fission bomb. The fission neutron production rate will exceed all neutron losses, and the neutron population will increase very rapidly and uncontrollably in a bomb, and at a controlled rate in a reactor. (See CRITICAL MASS, CRITICALITY).

SURFACE DOSE

The dose measured at the surface of a body. It is the sum of the air dose plus the dose due to backscatter from the object.

SURVEY INSTRUMENT (Radiation)

A portable instrument used for detecting and measuring radiation under varied physical conditions.

SUSCEPTIBILITY

The degree to which an individual respons to an exposure to a potentially harmful substance.

SYNCHROCYCLOTRON

A cyclotron in which the radiofrequency of the electric field is frequency-modulated to permit acceleration of particles to relativistic energies.

SYNCHROTRON

A device for accelerating particles, ordinarily electrons, in a circular orbit in an increasing magnetic field applied to synchronize with the orbital motion.

SYNDROME

The complex of symptoms associated with any disease.

SYNDROME, RADIATION

The complex of symptoms characterizing the disease known as radiation injury, resulting from excessive exposure of the whole (or a large part) body to ionizing radiation. The earliest of these symptoms are nausea,

vomiting, and diarrhea, which may be followed by loss of hair (epilation), hemorrhage, inflammation of the mouth and throat, and general loss of energy. In severe cases, where the radiation exposure has been relatively large, death may occur within two to four weeks. Those who survive 6 weeks after the receipt of a single dose of radiation may generally be expected to recover.

SYSTEMIC POISONING

Harmful effects caused by the distribution throughout the body of a toxic substance which has been absorbed by the bloodstream.

TAGGED COMPOUND

See LABELED COMPOUND.

TARGET THEORY (Direct Hit Theory)

Theory explaining some biologic effects of radiation on the basis of ionzation occurring in a very small sensitive region within the cell. One, two, or more "hits"; i.e., ionizing events within the sensitive volume, may be necessary to bring about the effect.

TENTH-VALUE LAYER

Amount of shielding material required to reduce the radiation level by a factor of 10. One TVL is equivalent to 3.3 half-value layer (HVL). Abbreviation: TVL.

TENTH-VALUE THICKNESS

The thickness of a given material which will decrease the amount (or dose) of gamma radiation to one-tenth of the amount incident upon it. Two tenth-value thicknesses will reduce the dose received by a factor of 10 x 10; i.e., 100, and so on. The tenth-value thickness of a given material depends on the gamma-ray energy; but for radiation of a particular energy, it is roughly inversely proportional to the density of the material.

THERMAL ENERGY

The energy emitted from the fireball as thermal radiation. The total amount of thermal energy received per unit area at a specified distance from a nuclear (or atomic) explosion is generally expressed in terms of calories per square centimeter. (See THERMAL RADIATION, TRANSMITTANCE).

THERMAL FLUX

Thermal radiation is measured in terms of calories per square centimeter incident on the target from the thermal radiation emitted by the fireball. The calorie is the amount of heat required to raise the temperature of 1 gram of water one degree centigrade at the initial temperature of 15° C.

THERMAL X-RAYS

The electromagnetic radiation, mainly in the soft x-ray region, emitted by the extremely hot weapon debris in virtue of its extremely high temperature; it is also referred to as the primary thermal radiation. It is the absorption of this radiation by the ambient medium, accompanied by an increase in temperature, which results in the formation of the fireball. (See WEAPON DEBRIS).

THERMIONIC EMISSION (in Scintillation Detectors)

The release of electrons from the dynode by heat rather than by radiation.

THERMONUCLEAR

An adjective referring to the process (or processes) in which very high temperatures are used to bring about the fusion of light nuclei, such as those of the hydrogen isotopes, deuterium and tritium, with the accompanying liberation of energy. A thermonuclear bomb is a weapon in which part of the explosion energy results from thermonuclear fusion reactions. The high temperatures required are obtained by means of a fission explosion. (See FUSION).

THIMBLE IONIZATION CHAMBER

A small cylindrical or spherical ionization chamber, usually with walls of organic material.

THRESHOLD DETECTOR

An element (or isotope) in which radioactivity is induced only by the capture of neutrons having energies in excess of a certain threshold value characteristic of the element (or isotope). Threshold detectors are used to determine the neutron spectrum from a nuclear (or atomic) explosion; i.e., the numbers of neutrons in various energy ranges.

THRESHOLD DOSE

The minimum dose that will produce a detectable degree of any given effect.

TISSUE DOSE

Radiation dose received by a tissue in the region of interest. In the case of x-rays and gamma rays, tissue doses are expressed in roentgens. At the present time, the rep is the generally accepted unit of tissue dose for other ionizing radiations.

TISSUE EQUIVALENT

Material which produces ionization essentially equivalent to that characteristic of tissue when irradiated.

TISSUE EQUIVALENT IONIZATION CHAMBER

Ionization chamber in which the material of the walls, electrodes, and gas are so selected as to produce ionization essentially equivalent to that characteristic of the tissue under consideration. In some cases it is sufficient to have only tissue equivalent walls, and the gas may be air, provided the air volume is negligibly small. The essential requisite in this case is that the contribution to the ionization in the air made by ionizing particles originating in the air is negligible compared to that produced by ionizing particles characteristic of the wall material.

TISSUE EQUIVALENT MATERIAL

Material made up of the same elements in the same proportions as they occur in some particular biological tissue. In some cases the equivalence may be approximated with sufficient accuracy on the basis of effective atomic number.

TOXIC

Capable of causing injury or illness in a living organism.

TOXICITY

The ability of a substance to produce injury or illness in a living organism.

TRACER, ISOTOPIC

The isotope or nonnatural mixture of isotopes of an element which may be incorporated into a sample to make possible observation of the course of that element, alone or in combination, through a chemical, biological, or physical process. The observations may be made by measurement of radioactivity or of isotopic abundance.

TRACK

Microscopically visible manifestation of the path of an ionizing particle in a nuclear emulsion.

TRANSMUTATION

a. Any process in which a nuclide is transformed into a different nuclide.

b. More specifically, the transformation of a nuclide into a different element by a nuclear reaction.

TUMOR

In its general sense, a swelling. The term is often synonymous with neoplasm.

ULTRAVIOLET

Electromagnetic radiation of a wavelength between the shortest visible violet (about 3850 Angstroms) and soft x-rays (about 100 Angstroms).

USEFUL BEAM (in Radiology)

That part of the primary radiation which passes through the aperture, cone, or other collimator.

VALENCE

The number representing the combining or displacing power of an atom; the number of electrons lost, gained, or shared by an atom in a compound; the number of hydrogen atoms with which an atom will combine, or which it will displace.

VALENCE ELECTRON

Electron which is gained, lost, or shared in a chemical reaction.

VAN DE GRAAF GENERATOR

An electrostatic generator which employs a system of conveyor belt and spray points to charge an insulated electrode to a high potential.

VAPOR

The gaseous form of substances which are normally in liquid or solid form.

WAVE MOTION

The transmission of a periodic motion or vibration through a medium or empty space. Transverse wave motion is that in which the vibration is perpendicular to the direction of propagation. Longitudinal wave motion is that in which the vibration is parallel to direction of propagation.

WAVELENGTH

The distance between any two similar points of two consecutive waves; for electromagnetic radiation, the wavelength is equal to the velocity of light (c) divided by the frequency of the wave (v).

WEIGHT

The force with which a body is attracted toward the earth. CGS units: gm-cm/sec^2.

WHOLE-BODY EXPOSURE

An exposure of the body to radiation, where the entire body rather than an isolated part is irradiated. Where a radioisotope is uniformly distributed throughout the body tissues, rather than being concentrated in certain parts, the irradiation can be considered as whole-body exposure.

WIPE SAMPLE

A sample made for the purpose of determining the presence of removable radioactive contamination on a surface. It is done by wiping, with slight pressure, a piece of soft filter paper over a representative type of surface area.

WORK

The transfer of energy by the application of a force through a distance. The product of force and the distance through which it moves.

X-RAYS

Penetrating electromagnetic radiation having wavelength very much shorter than those of visible light. They are usually produced by bombarding a metallic target with fast electrons in a high vacuum. In nuclear reactions it is customary to refer to photons originating in the nucleus as gamma rays, and to those originating in the extranuclear parts of the atom as x-rays. These rays are sometimes called roentgen rays, after their discoverer, W. K. Roentgen.

SECTION 32

CONVERSION TABLES

TO CONVERT	INTO	MULTIPLY BY
Abcoulomb	Statcoulombs	2.998×10^{10}
Acre	Sq. chain (Gunters)	10
Acre	Rods	160
Acre	Square links (gunters)	1×10^{5}
Acre	Hectare or sq. hectometer	.4047
acres	sq. feet	43,560.0
acres	sq. meters	4,047.
acres	sq. miles	1.562×10^{-3}
acres	sq. yards	4,840.
acre-feet	cu. feet	43,560.0
acre-feet	gallons	3.259×10^{5}
amperes/sq cm	amps/sq. in.	6.452
amperes/sq cm	amps/sq meter	10^{4}
amperes/sq in.	amps/sq cm	0.1550
amperes/sq in.	amps/sq meter	1,550.0
amperes/sq meter	amps/sq cm	10^{-4}
amperes/sq meter	amps/sq in.	6.452×10^{-4}
ampere-hours	coulombs	3,600.0
ampere-hours	faradays	0.03731
ampere-turns	gilberts	1.257
ampere-turns/cm	amp-turns/in.	2.540
ampere-turns/cm	amp-turns/meter	100.0
ampere-turns/cm	gilberts/cm	1.257
ampere-turns/in.	amp-turns/cm	0.3937
ampere-turns/in.	amp-turns/meter	39.37
ampere-turns/in.	gilberts/cm	0.4950
ampere-turns/meter	amp/turns/cm	0.01
ampere-turns/meter	amp-turns/in.	0.0254
ampere-turns/meter	gilberts/cm	0.01257
Angstrom unit	Inch	3937×10^{-9}
Angstrom unit	Meter	1×10^{-10}
Angstrom unit	Micron or (Mu)	1×10^{-4}
Are	Acre (US)	.02471
Ares	sq. yards	119.60
ares	acres	0.02471
ares	sq meters	100.0
Astronomical Unit	Kilometers	1.495×10^{8}
Atmospheres	Ton/sq. inch	.007348
atmospheres	cms of mercury	76.0
atmospheres	ft of water (at 4°C)	33.90
atmospheres	in. of mercury (at 0°C)	29.92
atmospheres	kgs/sq cm	1.0333
atmospheres	kgs/sq meter	10,332.
atmospheres	pounds/sq in.	14.70
atmospheres	tons/sq ft	1.058

TO CONVERT	INTO	MULTIPLY BY
Barrels (U.S.,dry)	cu. inches	7,056.
Barrels (U.S.,dry)	quarts (dry)	105.0
Barrels (U.S.,liquid)	gallons	31.5
barrels (oil)	gallons (oil)	42.0
bars	atmospheres	0.9869
bars	dynes/sq cm	10^6
bars	kgs/sq meter	1.020×10^4
bars	pounds/sq ft.	2,089.
bars	pounds/sq in.	14.50
Baryl	Dyne/sq. cm.	1.000
Bolt (US Cloth)	Meters	36.576
BTU	Liter-Atmosphere	10.409
Btu	ergs	1.0550×10^{10}
Btu	foot-lbs	778.3
Btu	gram-calories	252.0
Btu	horsepower-hrs	3.931×10^{-4}
Btu	joules	1,054.8
Btu	kilogram-calories	0.2520
Btu	kilogram-meters	107.5
Btu	kilowatt-hrs	2.928×10^{-4}
Btu/hr	foot-pounds/sec	0.2162
Btu/hr	gram-cal/sec	0.0700
Btu/hr	horsepower-hrs	3.929×10^{-4}
Btu/hr	watts	0.2931
Btu/min	foot-lbs/sec	12.96
Btu/min	horsepower	0.02356
Btu/min	kilowatts	0.01757
Btu/min	watts	17.57
Btu/sq ft/min	watts/sq in.	0.1221
Bucket (Br. dry)	Cubic Cm.	1.818×10^4
bushels	cu ft	1.2445
bushels	cu in.	2,150.4
bushels	cu meters	0.03524
bushels	liters	35.24
bushels	pecks	4.0
bushels	pints (dry)	64.0
bushels	quarts (dry)	32.0
Calories, gram (mean)	B.T.U. (mean)	3.9685×10^{-3}
Candle/sq. cm	Lamberts	3.142
Candle/sq. inch	Lamberts	.4870
centares (centiares)	sq meters	1.0
Centigrade	Fahrenheit	(C°x9/5) +32
centigrams	grams	0.01
Centiliter	Ounce fluid (US)	.3382
Centiliter	Cubic inch	.6103
Centiliter	drams	2.705
centiliters	liters	0.01
centimeters	feet	3.281×10^{-2}

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TO CONVERT	INTO	MULTIPLY BY
centimeters	inches	0.3937
centimeters	kilometers	10^{-5}
centimeters	meters	0.01
centimeters	miles	6.214×10^{-6}
centimeters	millimeters	10.0
centimeters	mils	393.7
centimeters	yards	1.094×10^{-2}
centimeter-dynes	cm-grams	1.020×10^{-3}
centimeter-dynes	meter-kgs	1.020×10^{-8}
centimeter-dynes	pound-feet	7.376×10^{-8}
centimeter-grams	cm-dynes	980.7
centimeter-grams	meter-kgs	10^{-5}
centimeter-grams	pound-feet	7.233×10^{-5}
centimeters of mercury	atmospheres	0.01316
centimeters of mercury	feet of water	0.4461
centimeters of mercury	kgs/sq meter	136.0
centimeters of mercury	pounds/sq ft	27.85
centimeters of mercury	pounds/sq in.	0.1934
centimeters/sec	feet/min	1.1969
centimeters/sec	feet/sec	0.03281
centimeters/sec	kilometers/hr	0.036
centimeters/sec	knots	0.1943
centimeters/sec	meters/min	0.6
centimeters/sec	miles/hr	0.02237
centimeters/sec	miles/min	3.728×10^{-4}
centimeters/sec/sec	feet/sec/sec	0.03281
centimeters/sec/sec	kms/hr/sec	0.036
centimeters/sec/sec	meters/sec/sec	0.01
centimeters/sec/sec	miles/hr/sec	0.02237
Chain	Inches	792.00
Chain	meters	20.12
Chains (surveyors' or Gunter's)	yards	22.00
circular mils	sq cms	5.067×10^{-6}
circular mils	sq mils	0.7854
Circumference	Radians	6.283
circular mils	sq inches	7.854×10^{-7}
Cords	cord feet	8
Cord feet	cu. feet	16
Coulomb	Statcoulombs	2.998×10^{9}
coulombs	faradays	1.036×10^{-5}
coulombs/sq cm	coulombs/sq in.	64.52
coulombs/sq cm	coulombs/sq meter	10^{4}
coulombs/sq in.	coulombs/sq cm	0.1550
coulombs/sq in.	coulombs/sq meter	1,550.
coulombs/sq meter	coulombs/sq cm	10^{-4}
coulombs/sq meter	coulombs/sq in.	6.452×10^{-4}
cubic centimeters	cu feet	3.531×10^{-5}
cubic centimeters	cu inches	0.06102

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TO CONVERT	INTO	MULTIPLY BY
cubic centimeters	cu meters	10^{-6}
cubic centimeters	cu yards	1.308×10^{-6}
cubic centimeters	gallons (U.S. liq.)	2.642×10^{-4}
cubic centimeters	liters	0.001
cubic centimeters	pints (U.S. liq.)	2.113×10^{-3}
cubic centimeters	quarts (U.S. liq.)	1.057×10^{-3}
cubic feet	bushels (dry)	0.8036
cubic feet	cu cms	28,320.0
cubic feet	cu inches	1,728.0
cubic feet	cu meters	0.02832
cubic feet	cu yards	0.03704
cubic feet	gallons (U.S. liq.)	7.48052
cubic feet	liters	28.32
cubic feet	pints (U.S. liq.)	59.84
cubic feet	quarts (U.S. liq.)	29.92
cubic feet/min	cu cms/sec	472.0
cubic feet/min	gallons/sec	0.1247
cubic feet/min	liters/sec	0.4720
cubic feet/min	pounds of water/min	62.43
cubic feet/sec	million gals/day	0.646317
cubic feet/sec	gallons/min	448.831
cubic inches	cu cms	16.39
cubic inches	cu feet	5.787×10^{-4}
cubic inches	cu meters	1.639×10^{-5}
cubic inches	cu yards	2.143×10^{-5}
cubic inches	gallons	4.329×10^{-3}
cubic inches	liters	0.01639
cubic inches	mil-feet	1.061×10^{5}
cubic inches	pints (U.S. liq.)	0.03463
cubic inches	quarts (U.S. liq.)	0.01732
cubic meters	bushels (dry)	28.38
cubic meters	cu cms	10^{6}
cubic meters	cu feet	35.31
cubic meters	cu inches	61,023.0
cubic meters	cu yards	1.308
cubic meters	gallons (U.S. liq.)	264.2
cubic meters	liters	1,000.0
cubic meters	pints (U.S. liq.)	2,113.0
cubic meters	quarts (U.S. liq.)	1,057.
cubic yards	cu cms	$7{,}646 \times 10^{5}$
cubic yards	cu feet	27.0
cubic yards	cu inches	46,656.0
cubic yards	cu meters	0.7646
cubic yards	gallons (U.S. liq.)	202.0
cubic yards	liters	764.6
cubic yards	pints (U.S. liq.)	1,615.9
cubic yards	quarts (U.S. liq.)	807.9
cubic yards/min	cubic ft/sec	0.45
cubic yards/min	gallons/sec	3.367
cubic yards/min	liters/sec	12.74

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TO CONVERT	INTO	MULTIPLY BY
Dalton	Gram	1.650×10^{-24}
days	seconds	86,400.0
decigrams	grams	0.1
deciliters	liters	0.1
decimeters	meters	0.1
degrees (angle)	quadrants	0.01111
degrees (angle)	radians	0.01745
degrees (angle)	seconds	3,600.0
degrees/sec	radians/sec	0.01745
degrees/sec	revolutions/min	0.1667
degrees/sec	revolutions/sec	2.778×10^{-3}
dekagrams	grams	10.0
dekaliters	liters	10.0
dekameters	meters	10.0
Drams (apothecaries' or troy)	ounces (avoidupois)	0.1371429
Drams (apothecaries' or troy)	ounces (troy)	0.125
Drams (U.S., fluid or apoth.)	cubic cm.	3.6967
drams	grams	1.7718
drams	grains	27.3437
drams	ounces	0.0625
Dyne/cm	Erg/sq. millimeter	.01
Dyne/sq. cm.	Atmospheres	9.869×10^{-7}
Dyne/sq. cm.	Inch of Mercury at 0°C	2.953×10^{-5}
Dyne/sq. cm.	Inch of Water at 4°C	4.015×10^{-4}
dynes	grams	1.020×10^{-3}
dynes	joules/cm	10^{-7}
dynes	joules/meter (newtons)	10^{-5}
dynes	kilograms	1.020×10^{-6}
dynes	poundals	7.233×10^{-5}
dynes	pounds	2.248×10^{-6}
dynes/sq cm	bars	10^{-6}
Ell	Cm.	114.30
Ell	Inches	45
Em, Pica	Inch	.167
Em, Pica	Cm.	.4233
Erg/sec	Dyne-cm/sec	1.000
ergs	Btu	9.480×10^{-11}
ergs	dyne-centimeters	1.0
ergs	foot-pounds	7.367×10^{-8}
ergs	gram-calories	0.2389×10^{-7}
ergs	gram-cms	1.020×10^{-3}
ergs	horsepower-hrs	3.7250×10^{-14}
ergs	joules	10^{-7}
ergs	kg-calories	2.389×10^{-11}
ergs	kg-meters	1.020×10^{-8}
ergs	kilowatt-hrs	0.2778×10^{-13}
ergs	watt-hours	0.2778×10^{-10}
ergs/sec	Btu/min	$5,688 \times 10^{-9}$

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TO CONVERT	INTO	MULTIPLY BY
ergs	ft-lbs/min	4.427×10^{-6}
ergs/sec	ft-lbs/sec	7.3756×10^{-8}
ergs/sec	horsepower	1.341×10^{-10}
ergs/sec	kg-calories/min	1.433×10^{-9}
farads	microfarads	10^{6}
Faraday/sec	Ampere (absolute)	9.6500×10^{4}
faradays	ampere-hours	26.80
faradays	coulombs	9.649×10^{4}
Fathom	Meter	1.828804
fathoms	feet	6.0
feet	centimeters	30.48
feet	kilometers	3.048×10^{-4}
feet	meters	0.3048
feet	miles (naut.)	1.645×10^{-4}
feet	miles (stat.)	1.894×10^{-4}
feet	millimeters	304.8
feet	mils	1.2×10^{-4}
feet of water	atmospheres	0.02950
feet of water	in. of mercury	0.8826
feet of water	kgs/sq cm	0.03048
feet of water	kgs/sq meter	304.8
feet of water	pounds/sq ft	62.43
feet of water	pounds/sq in.	0.4335
feet/min	cms/sec	0.5080
feet/min	feet/sec	0.01667
feet/min	kms/hr	0.01829
feet/min	meters/min	0.3048
feet/min	miles/hr	0.01136
feet/sec	cms/sec	30.48
feet/sec	kms/hr	1.097
feet/sec	knots	0.5921
feet/sec	meters/min	18.29
feet/sec	miles/hr	0.6818
feet/sec	miles/min	0.01136
feet/sec/sec	cms/sec/sec	30.48
feet/sec/sec	kms/hr/sec	1.097
feet/sec/sec	meters/sec/sec	0.3048
feet/sec/sec	miles/hr/sec	0.6818
feet/100 feet	per cent grade	1.0
Foot-candle	Lumen/sq. meter	10.764
foot-pounds	Btu	1.286×10^{-3}
foot-pounds	ergs	1.356×10^{-7}
foot-pounds	gram-calories	0.3238
foot-pounds	hp-hrs	5.050×10^{-7}
foot-pounds	joules	1.356
foot-pounds	kg-calories	3.24×10^{-4}
foot-pounds	kg-meters	0.1383

TO CONVERT	INTO	MULTIPLY BY
foot-pounds	kilowatt-hrs	3.766×10^{-7}
foot-pounds/min	Btu/min	1.286×10^{-3}
foot-pounds/min	foot-pounds/sec	0.01667
foot-pounds/min	horsepower	3.030×10^{-5}
foot-pounds/min	kg-calories/min	3.24×10^{-4}
foot-pounds/min	kilowatts	2.260×10^{-5}
foot-pounds/sec	Btu/hr	4.6263
foot-pounds/sec	Btu/min	0.07717
foot-pounds/sec	horsepower	1.818×10^{-3}
foot-pounds/sec	kg-calories/min	0.01945
foot-pounds/sec	kilowatts	1.356×10^{-3}
Furlongs	miles (U.S.)	0.125
furlongs	rods	40.0
furlongs	feet	660.0
gallons	cu cms	3,785.0
gallons	cu feet	0.1337
gallons	cu inches	231.0
gallons	cu meters	3.785×10^{-3}
gallons	cu yards	4.951×10^{-3}
gallons	liters	3.785
gallons (liq. Br. Imp.)	gallons (U.S. Liq.)	1.20095
gallons (U.S.)	gallons (Imp.)	0.83267
gallons of water	pounds of water	8.3453
gallons/min	cu ft/sec	2.228×10^{-3}
gallons/min	liters/sec	0.06308
gallons/min	cu ft/hr	8.0208
gausses	lines/sq in.	6.452
gausses	webers/sq cm	10^{-8}
gausses	webers/sq in.	6.452×10^{-8}
gausses	webers/sq meter	10^{-4}
gilberts	ampere-turns	0.7958
gilberts/cm	amp-turns/cm	0.7958
gilberts/cm	amp-turns/in	2.021
gilberts/cm	amp-turns/meter	79.58
Gills (British)	cubic cm.	142.07
gills	liter	0.1183
gills	pints (liq.)	0.25
Grade	Radian	.01571
Grains	drams (avoirdupois)	0.03657143
grains (troy)	grains (avdp)	1.0
grains (troy)	grains	0.06480
grains (troy)	ounces (avdp)	2.0833×10^{-3}
grains (troy)	pennyweight (troy)	0.04167
grains/U.S. gal	parts/million	17.118
grains/U.S. gal	pounds/million gal	142.86
grains/Imp. gal	parts/million	14.286
grams	dynes	980.7
grams	grains	15.43

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TO CONVERT	INTO	MULTIPLY BY
grams	joules/cm	9.807×10^{-5}
grams	joules/meter (newtons)	9.807×10^{-3}
grams	kilograms	0.001
grams	milligrams	1.000.
grams	ounces (avdp)	0.03527
grams	ounces (troy)	0.03215
grams	poundals	0.07093
grams	pounds	2.205×10^{-3}
grams/cm	pounds/inch	5.600×10^{-3}
grams/cu cm	pounds/cu ft	62.43
grams/cu cm	pounds/cu in	0.03613
grams/cu cm	pounds/mil-foot	3.405×10^{-7}
grams/liter	grains/gal	58.417
grams/liter	pounds/1,000 gal	8.345
grams/liter	pounds/cu ft	0.062427
grams/liter	parts/million	1,000.0
grams/sq cm	pounds/sq ft	2.0481
gram-calories	Btu	3.9683×10^{-3}
gram-calories	ergs	4.1868×10^{7}
gram-calories	foot-pounds	3.0880
gram-calories	horespower-hrs	1.5596×10^{-6}
grams-calories	kilowatt-hrs	1.1630×10^{-6}
grams-calories	watt-hrs	1.1630×10^{-3}
grams-calories/sec	Btu/hr	14.286
gram-centimeters	Btu	9.297×10^{-8}
gram-centimeters	ergs	980.7
gram-centimeters	joules	9.807×10^{-5}
gram-centimeters	kg-cal	2.343×10^{-8}
gram-centimeters	kg-meters	10^{-5}
Hand	Cm.	10.16
hectares	acres	2.471
hectares	sq feet	1.076×10^{5}
hectograms	grams	100.0
hectoliters	liters	100.0
hectometers	meters	100.0
hectowatts	watts	100.0
henries	millihenries	1,000.0
Hogsheads (British)	cubic ft.	10.114
Hogsheads (U.S.)	cubic ft.	8.42184
Hogsheads (U.S.)	gallons (U.S.)	63
horsepower	Btu/min	42.44
horsepower	foot-lbs/min	33,000.
horsepower	foot-lbs/sec	550.0
horsepower (metric) (542.5 ft lb/sec)	horsepower (550 ft lb/sec)	0.9863
horsepower (550 ft lb/sec)	horsepower (metric) (542.5 ft lb/sec)	1.014
horsepower	kg-calories/min	10.68

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TO CONVERT	INTO	MULTIPLY BY
horsepower	kilowatts	0.7457
horsepower	watts	745.7
horsepower (boiler)	Btu/hr	33,479
horsepower (boiler)	kilowatts	9.803
horsepower-hrs	Btu	2,547.
horsepower-hrs	ergs	2.6845×10^{13}
horsepower-hrs	foot-lbs	1.98×10^{6}
horsepower-hrs	gram-calories	641,190.
horsepower-hrs	joules	2.684×10^{6}
horsepower-hrs	kg-calories	641.1
horsepower-hrs	kg-meters	2.737×10^{5}
horsepower-hrs	kilowatt-hrs	0.7457
hours	days	4.167×10^{-2}
hours	weeks	5.952×10^{-3}
Hundredweights (long)	pounds	112
Hundredweights (long)	tons (long)	0.05
Hundredweights (short)	ounces (avoirdupois)	1600
Hundredweights (short)	pounds	100
Hundredweights (shorts)	tons (metric)	0.0453592
Hundredweights (short)	tons (long)	0.0446429
inches	centimeters	2.540
inches	meters	2.540×10^{-2}
inches	miles	1.578×10^{-5}
inches	millimeters	25.40
inches	mils	1,000.0
inches	yards	2.778×10^{-2}
inches of mercury	atmospheres	0.03342
inches of mercury	feet of water	1.133
inches of mercury	kgs/sq cm	0.03453
inches of mercury	kgs/sq meter	345.3
inches of mercury	pounds/sq ft	70.73
inches of mercury	pounds/sq in.	0.4912
inches of water (at 4°C)	atmospheres	2.458×10^{-3}
inches of water (at 4°C)	inches of mercury	0.07355
inches of water (at 4°C)	kgs/sq cm	2.540×10^{-3}
inches of water (at 4°C)	ounces/sq in.	0.5781
inches of water (at 4°C)	pounds/sq ft	5.204
inches of water (at 4°C)	pounds/sq in.	0.03613
International Ampere	Ampere (absolute)	.9998
International Volt	Volts (absolute)	1.0003
International volt	Joules (absolute)	$1\text{-}593 \times 10^{-19}$
International volt	Joules	9.654×10^{4}
kilograms	dynes	980,665.
kilograms	grams	1,000.0
kilograms	joules/cm	0.09807
kilograms	joules/meter (newtons)	9.807

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TO CONVERT	INTO	MULTIPLY BY
kilograms	poundals	70.93
kilograms	pounds	2.205
kilograms	tons (long)	9.842×10^{-4}
kilograms	tons (short)	1.102×10^{-3}
kilograms/cu meter	grams/cu cm	0.001
kilograms/cu meter	pounds/cu ft	0.06243
kilograms/cu meter	pounds/cu in.	3.613×10^{-5}
kilograms/cu meter	pounds/mil-foot	3.405×10^{10}
kilograms/meter	pounds/ft	0.6720
kilograms/sq. cm.	Dynes	980,665
kilograms/sq cm	atmospheres	0.9678
kilograms/sq cm	feet of water	32.81
kilograms/sq cm	inches of mercury	28.96
kilograms/sq cm	pounds/sq ft	2,048.
kilograms/sq cm	pounds/sq in.	14.22
kilograms/sq meter	atmospheres	9.678×10^{-5}
kilograms/sq meter	bars	98.07×10^{-6}
kilograms/sq meter	feet of water	3.281×10^{-3}
kilograms/sq meter	inches of mercury	2.896×10^{-3}
kilograms/sq meter	pounds/sq ft	0.2048
kilograms/sq meter	pounds/sq in.	1.422×10^{-3}
kilograms/sq mm	kgs/sq meter	10^{6}
kilogram-calories	Btu	3.968
kilogram-calories	foot-pounds	3,088.
kilogram-calories	hp-hrs	1.560×10^{-3}
kilogram-calories	joules	4,186.
kilogram-calories	kg-meters	426.9
kilogram-calories	kilojoules	4.186
kilogram-calories	kilowatt-hrs	1.163×10^{-3}
kilogram meters	Btu	9.294×10^{-3}
kilogram meters	ergs	9.804×10^{7}
kilogram meters	foot-pounds	7.233
kilogram meters	joules	9.804
kilogram meters	kg-calories	2.342×10^{-3}
kilogram meters	kilowatt-hrs	2.723×10^{-6}
kilolines	maxwells	1,000.0
kiloliters	liters	1,000.0
kilometers	centimeters	10^{5}
kilometers	feet	3,281.
kilometers	inches	3.937×10^{4}
kilometers	meters	1,000.0
kilometers	miles	0.6214
kilometers	millimeters	10^{6}
kilometers	yards	1,094.
kilometers/hr	cms/sec	27.78
kilometers/hr	feet/min	54.68
kilometers/hr	feet/sec	0.9113
kilometers/hr	knots	0.5396
kilometers/hr	meters/min	16.67
kilometers/hr	miles/hr	0.6214
kilometers/hr/sec	cms/sec/sec	27.78

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TO CONVERT	INTO	MULTIPLY BY
kilometers/hr/sec	ft/sec/sec	0.9113
kilometers/hr/sec	meters/sec/sec	0.2778
kilometers/hr/sec	miles/hr/sec	0.6214
kilowatts	Btu/min	56.92
kilowatts	foot-lbs/min	4.426×10^4
kilowatts	foot-lbs/sec	737.6
kilowatts	horsepower	1.341
kilowatts	kg-calories/min	14.34
kilowatts	watts	1,000.0
kilowatt-hrs	Btu	3,413.
kilowatt-hrs	ergs	3.600×10^{13}
kilowatt-hrs	foot-lbs	2.655×10^6
kilowatt-hrs	gram-calories	859,850.
kilowatt-hrs	horsepower-hrs	1.341
kilowatt-hrs	joules	3.6×10^6
kilowatt-hrs	kg-calories	860.5
kilowatt-hrs	kg-meters	3.671×10^5
kilowatt-hrs	pounds of water evaporated from and at 212°F	3.53
kilowatt-hrs	pounds of water raised from 65° to 212° F.	22.75
knots	feet/hr	6,080.
knots	kilometers/hr	1.8532
knots	nautical miles/hr	1.0
knots	statute miles/hr	1.151
knots	yards/hr	2,027.
knots	feet/sec	1.689
league	miles (approx.)	3.0
Light year	Miles	5.9×10^{12}
Light year	Kilometers	9.46091×10^{12}
lines/sq cm	gausses	1.0
lines/sq in.	gausses	0.1550
lines/sq in.	webers/sq cm	1.550×10^{-9}
lines/sq in.	webers/sq in.	10^{-8}
lines/sq in.	webers/sq meter	1.550×10^{-5}
links (engineer's)	inches	12.0
links (surveyor's)	inches	7.92
liters	bushels (U.S. dry)	0.02838
liters	cu cm	1,000.0
liters	cu feet	0.03531
liters	cu inches	61.02
liters	cu meters	0.001
liters	cu yards	1.308×10^{-3}
liters	gallons (U.S. liq.)	0.2642
liters	pints (U.S. liq.)	2.113
liters	quarts (U.S. liq.)	1.057
liters/min	cu ft/sec	5.886×10^{-4}

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TO CONVERT	INTO	MULTIPLY BY
liters/min	gals/sec	4.403×10^{-3}
lumens/sq ft	foot-candles	1.0
Lumen	Spherical candle power	.07958
Lumen	Watt	.001496
Lumen/sq ft.	Lumen/sq. meter	10.76
lux	foot-candles	0.0929
maxwells	kilolines	0.001
maxwells	webers	10^{-8}
megalines	maxwells	10^{6}
megohms	microhms	10^{12}
megohms	ohms	10^{6}
meters	centimeters	100.0
meters	feet	3.281
meters	inches	39.37
meters	kilometers	0.001
meters	miles (naut.)	5.396×10^{-4}
meters	miles (stat.)	6.214×10^{-4}
meters	millimeters	1,000.0
meters	yards	1.094
meters	varas	1.179
meters/min	cms/sec	1.667
meters/min	feet/min	3.281
meters/min	feet/sec	0.05468
meters/min	kms/hr	0.06
meters/min	knots	0.03238
meters/min	miles/hr	0.03728
meters/sec	feet/min	196.8
meters/sec	feet/sec	3.281
meters/sec	kilometers/hr	3.6
meters/sec	kilometers/min	0.06
meters/sec	miles/hr	2.237
meters/sec	miles/min	0.03728
meters/sec/sec	cms/sec/sec	100.0
meters/sec/sec	ft/sec/sec	3.281
meters/sec/sec	kms/hr/sec	3.6
meters/sec/sec	miles/hr/sec	2.237
meter-kilograms	cm-dynes	9.807×10^{7}
meter-kilograms	cm-grams	10^{5}
meter-kilograms	pound-feet	7.233
microfarad	farads	10^{-6}
micrograms	grams	10^{-6}
microhms	megohms	10^{12}
microhms	ohms	10^{-6}
microliters	liters	10^{-6}
Microns	meters	1×10^{-6}
miles (naut.)	feet	6,080.27
miles (naut.)	kilometers	1.853

TO CONVERT	INTO	MULTIPLY BY
miles (naut.)	meters	1,853.
miles (naut.)	miles (statute)	1.1516
miles (naut.)	yards	2,027.
miles (statute)	centimeters	1.609×10^5
miles (statute)	feet	5,280.
miles (statute)	inches	6.336×10^4
miles (statute)	kilometers	1.609
miles (statute)	meters	1,609.
miles (statute)	miles (naut.)	0.8684
miles (statute)	yards	1,760.
miles/hr	cms/sec	44.70
miles/hr	feet/min	88.
miles/hr	feet/sec	1.467
miles/hr	kms/hr	1.609
miles/hr	kms/min	0.02682
miles/hr	knots	0.8684
miles/hr	meters/min	26.82
miles/hr	miles/min	0.1667
miles/hr/sec	cms/sec/sec	44.70
miles/hr/sec	feet/sec/sec	1.467
miles/hr/sec	kms/hr/sec	1.609
miles/hr/sec	meters/sec/sec	0.4470
miles/min	cms/sec	2,682.
miles/min	feet/sec	88.
miles/min	kms/min	1.609
miles/min	knots/min	0.8684
miles/min	miles/hr	60.0
mil-feet	cu inches	9.425×10^{-6}
milliers	kilograms	1,000.
Millimocrons	meters	1×10^{-9}
Milligrams	grains	0.01543236
milligrams	grains	0.001
milligrams/liter	parts/million	1.0
millihenries	henries	0.001
milliliters	liters	0.001
millimeters	centimeters	0.1
millimeters	feet	3.281×10^{-3}
millimeters	inches	0.03937
millimeters	kilometers	10^{-6}
millimeters	meters	0.001
millimeters	miles	6.214×10^{-7}
millimeters	mils	39.37
millimeters	yards	1.094×10^{-3}
million gals/day	cu ft/sec	1.54723
mils	centimeters	2.540×10^{-3}
mils	feet	8.333×10^{-5}
mils	inches	0.001
mils	kilometers	2.540×10^{-8}
mils	yards	2.778×10^{-5}

TO CONVERT	INTO	MULTIPLY BY
miner's inches	cu ft/min	1.5
Minims (British)	cubic cm.	0.059192
Minims (U.S., fluid)	cubic cm.	0.061612
minutes (angles)	degrees	0.01667
minutes (angles)	quadrants	1.852×10^{-4}
minutes (angles)	radians	2.909×10^{-4}
minutes (angles)	seconds	60.0
myriagrams	kilograms	10.0
myriameters	kilometers	10.0
myriawatts	kilowatts	10.0
nepers	decibels	8.686
Newton	Dynes	1×10^{5}
OHM (International)	OHM (absolute)	1.0005
ohms	megohms	10^{6}
ohms	microhms	10^{-6}
ounces	drams	16.0
ounces	grains	437.5
ounces	grams	28.349527
ounces	pounds	0.0625
ounces	ounces (troy)	0.9115
ounces	tons (long)	2.790×10^{-5}
ounces	tons (metric)	2.835×10^{-5}
ounces (fluid)	cu inches	1.805
ounces (fluid)	liters	0.02957
ounces (troy)	grains	480.0
ounces (troy)	grams	31.103481
ounces (troy)	ounces (avdp.)	1.09714
ounces (troy)	pennyweights (troy)	20.0
ounces (troy)	pounds (troy)	0.08333
Ounce/sq. inch	Dynes/sq. cm.	4309
ounces/sq in.	pounds/sq in.	0.0625
Parsec	Miles	19×10^{12}
Parsec	kilometers	3.084×10^{13}
parts/million	grains/U.S. Gal	0.0584
parts/million	grains/Imp. gal	0.07016
parts/million	pounds/million gal	8.345
Pecks (British)	cubic inches	554.6
Pecks (British)	liters	9.091901
Pecks (U.S.)	bushels	0.25
Pecks (U.S.)	cubic inches	537.605
Pecks (U.S.)	liters	8.809582
Pecks (U.S.)	quarts (dry)	8
pennyweights (troy)	grains	24.0
pennyweights (troy)	ounces (troy)	0.05
pennyweights (troy)	grams	1.55517

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TO CONVERT	INTO	MULTIPLY BY
pennyweights (troy)	pounds (troy)	4.1667×10^{-3}
pints (dry)	cu inches	33.60
pints (liq)	cu cms.	473.2
pints (liq)	cu feet	0.01671
pints (liq)	cu inches	28.87
pints (liq)	cu meters	4.732×10^{-4}
pints (liq)	cu yards	6.189×10^{-4}
pints (liq)	gallons	0.125
pints (liq)	liters	0.4732
pints (liq)	quarts (liq)	0.5
Planck's quantum	Erg-second	6.624×10^{-27}
Poise	Gram/cm. sec.	1.00
Pounds (avoirdupois)	ounces (troy)	14.5833
poundals	dynes	13,826.
poundals	grams	14.10
poundals	joules/cm	1.383×10^{-3}
poundals	joules/meter (newtons)	0.1383
poundals	kilograms	0.01410
poundals	pounds	0.03108
pounds	drams	256.
pounds	dynes	44.4823×10^{4}
pounds	grains	7,000.
pounds	grams	453.5924
pounds	joules/cm	0.04448
pounds	joules/meter (newton)	4.448
pounds	kilograms	0.4536
pounds	ounces	16.0
pounds	ounces (troy)	14.5833
pounds	poundals	32.17
pounds	pounds (troy)	1.21528
pounds	tons (short)	0.0005
pounds (troy)	grains	5,760.
pounds (troy)	grams	373.24177
pounds (troy)	ounces (avdp.)	13.1657
pounds (troy)	ounces (troy)	12.0
pounds (troy)	pennyweights (troy)	240.0
pounds (troy)	pounds (avdp.)	0.822857
pounds (troy)	tons (long)	3.6735×10^{-4}
pounds (troy)	tons (metric)	3.7324×10^{-4}
pounds (troy)	tons (short)	4.1143×10^{-4}
pounds of water	cu feet	0.01602
pounds of water	cu inches	27.68
pounds of water	gallons	0.1198
pounds of water/min	cu ft/sec	2.670×10^{-4}
pound-feet	cm-dynes	1.356×10^{7}
pound-feet	cm-grams	13,825.
pound-feet	meter-kgs	0.1383
pounds/cu ft	grams/cu cm	0.01602
pounds/cu ft	kgs/cu meter	16.02
pounds/cu ft	pounds/cu in.	5.787×10^{-4}

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TO CONVERT	INTO	MULTIPLY BY
pounds/cu ft	pounds/mil-foot	5.456×10^{-9}
pounds/cu in.	gms/cu cm	27.68
pounds/cu in.	kgs/cu meter	2.768×10^{4}
pounds/cu in.	pounds/cu ft	1,728.
pounds/cu in.	pounds/mil-foot	9.425×10^{-6}
pounds/ft	kgs/meter	1.488
pounds/in.	gms/cm	178.6
pounds/mil-foot	gms/cu cm	2.306×10^{6}
pounds/sq ft	atmospheres	4.725×10^{-4}
pounds/sq ft	feet of water	0.01602
pounds/sq ft	inches of mercury	0.01414
pounds/sq ft	kgs/sq meter	4.882
pounds/sq ft	pounds/sq in.	6.944×10^{-3}
pounds/sq in.	atmospheres	0.06804
pounds/sq in.	feet of water	2.307
pounds/sq in.	inches of mercury	2.036
pounds/sq in.	kgs/sq meter	703.1
pounds/sq in.	pounds/sq ft	144.0
quadrants (angle)	degrees	90.0
quadrants (angle)	minutes	5,400.0
quadrants (angle)	radians	1.571
quadrants (angle)	seconds	3.24×10^{5}
quarts (dry)	cu inches	67.20
quarts (liq.)	cu cms	946.4
quarts (liq.)	cu feet	0.03342
quarts (liq.)	cu inches	57.75
quarts (liq.)	cu meters	9.464×10^{-4}
quarts (liq.)	cu yards	1.238×10^{-3}
quarts (liq.)	gallons	0.25
quarts (liq.)	liters	0.9463
radians	degrees	57.30
radians	minutes	3,438.
radians	quadrants	0.6366
radians	seconds	2.063×10^{5}
radians/sec	degrees/sec	57.30
radians/sec	revolutions/min	9.549
radians/sec	revolutions/sec	0.1592
radians/sec/sec	revs/min/min	573.0
radians/sec/sec	revs/min/sec	9.549
radians/sec/sec	revs/sec/sec	0.1592
revolutions	degrees	360.0
revolutions	quadrants	4.0
revolutions	radians	6.283
revolutions/min	degrees/sec	6.0
revolutions/min	radians/sec	0.1047
revolutions/min	revs/sec	0.01667

TO CONVERT	INTO	MULTIPLY BY
revolutions/min/min	radians/sec/sec	1.745×10^{-3}
revolutions/min/min	revs/min/sec	0.01667
revolutions/min/min	revs/sec/sec	2.778×10^{-4}
revolutions/sec	degrees/sec	360.0
revolutions/sec	radians/sec	6.283
revolutions/sec	revs/min	60.0
revolutions/sec/sec	radians/sec/sec	6.283
revolutions/sec/sec	revs/min/min	3,600.0
revolutions/sec/sec	revs/min/sec	60.0
Rod	Chain (Gunters)	.25
Rod	Meters	5.029
Rods (Surveyors' meas.)	yards	5.5
rods	feet	16.5
Scruples	grains	20
seconds (angle)	degrees	2.778×10^{-4}
seconds (angle)	minutes	0.01667
seconds (angle)	quadrants	3.087×10^{-6}
seconds (angle)	radians	4.848×10^{-6}
Slug	Kilogram	14.59
Slug	Pounds	32.17
Sphere	Steradians	12.57
square centimeters	circular mils	1.973×10^{5}
square centimeters	sq feet	1.076×10^{-3}
square centimeters	sq inches	0.1550
square centimeters	sq meters	0.0001
square centimeters	sq miles	3.861×10^{-11}
square centimeters	sq millimeters	100.0
square centimeters	sq yards	1.196×10^{-4}
square feet	acres	2.296×10^{-5}
square feet	circular mils	1.833×10^{8}
square feet	sq cms	929.0
square feet	sq inches	144.0
square feet	sq meters	0.09290
square feet	sq miles	3.587×10^{-8}
square feet	sq millimeters	9.290×10^{4}
square feet	sq yards	0.1111
square inches	circular mils	1.273×10^{6}
square inches	sq cms	6.452
square inches	sq feet	6.944×10^{-3}
square inches	sq millimeters	645.2
square inches	sq mils	10^{6}
square inches	sq yards	7.716×10^{-4}
square kilometers	acres	247.1
square kilometers	sq cms	10^{10}
square kilometers	sq ft	10.76×10^{6}
square kilometers	sq inches	1.550×10^{9}
square kilometers	sq meters	10^{6}
square kilometers	sq miles	0.3861

TO CONVERT	INTO	MULTIPLY BY
square kilometers	sq yards	1.196×10^6
square meters	acres	2.471×10^{-4}
square meters	sq cms	10^4
square meters	sq feet	10.76
square meters	sq inches	1,550.
square meters	sq miles	3.861×10^{-7}
square meters	sq millimeters	10^6
square meters	sq yards	1.196
square miles	acres	640.0
square miles	sq feet	27.88×10^6
square miles	sq kms	2.590
square miles	sq meters	2.590×10^6
square miles	sq yards	3.098×10^6
square millimeters	circular mils	1,973.
square millimeters	sq cms	0.01
square millimeters	sq feet	1.076×10^{-5}
square millimeters	sq inches	1.550×10^{-3}
square mils	circular mils	1.273
square mils	sq cms	6.452×10^{-6}
square mils	sq inches	10^{-6}
square yards	acres	2.066×10^{-4}
square yards	sq cms	8,361.
square yards	sq feet	9.0
square yards	sq inches	1,296.
square yards	sq meters	0.8361
square yards	sq miles	3.228×10^{-7}
square yards	sq millimeters	8.361×10^5
temperature (°C)+273	absolute temperature (°C)	1.0
temperature (°C)+ 17.78	temperature (°F)	1.8
temperature (°F) + 460	absolute temperature (°F)	1.0
temperature (°F)-32	temperature (°C)	5/9
tons (long)	kilograms	1,016.
tons (long)	pounds	2,240.
tons (long)	tons (short)	1.120
tons (metric)	kilograms	1,000.
tons (metric)	pounds	2,205
tons (short)	kilograms	907.1848
tons (short)	ounces	32,000.
tons (short)	ounces (troy)	29,166.66
tons (short)	pounds	2,000.
tons (short)	pounds (troy)	2,430.56
tons (short)	tons (long)	0.89287
tons (short)	tons (metric)	0.9078
tons (short) sq ft	kgs/sq meter	9,765.
tons (short) sq ft	pounds/sq in.	2,000.

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TO CONVERT	INTO	MULTIPLY BY
tons of water/24 hrs	pounds of water/hr	83.333
tons of water/24 hrs	gallons/min	0.16643
tons of water/24 hrs	cu ft/hr	1.3349
Volt/inch	Volt/cm.	.39370
Volt (absolute)	Statvolts	.003336
watts	Btu/hr	3.4129
watts	Btu/min	0.05688
watts	ergs/sec	107.
watts	foot-lbs/min	44.27
watts	foot-lbs/sec	0.7378
watts	horsepower	1.341×10^{-3}
watts	horsepower (metric)	1.360×10^{-3}
watts	kg-calories/min	0.01433
watts	kilowatts	0.001
Watts (Abs)	B.T.U. (mean)/min.	0.056884
Watts (Abs.)	joules/sec	1
watt-hours	Btu	3.413
watt-hours	ergs	3.60×10^{10}
watt-hours	foot-pounds	2,656.
watt-hours	gram-calories	859.85
watt-hours	horsepower-hrs	1.341×10^{-3}
watt-hours	kilogram-calories	0.8605
watt-hours	kilogram-meters	367.2
watt-hours	kilowatt-hrs	0.001
Watt (International)	Watt (absolute)	1.0002
webers	maxwells	10^{8}
webers	kilolines	10^{5}
webers/sq in.	gausses	1.550×10^{7}
webers/sq in.	lines/sq in.	10^{8}
webers/sq in.	webers/sq cm	0.1550
webers/sq in.	webers/sq meter	1,550.
webers/sq meter	gausses	10^{4}
webers/sq meter	lines/sq in.	6.452×10^{4}
webers/sq meter	webers/sq cm	10^{-4}
webers/sq meter	webers/sq in.	6.452×10^{-4}
yards	centimeters	91.44
yards	kilometers	9.144×10^{4}
yards	meters	0.9144
yards	miles (naut.)	4.934×10^{-4}
yards	miles (stat.)	5.682×10^{-4}
yards	millimeters	914.4

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CONVERSION FACTORS

AREA

Multiply # of → / to obtain # of ←	by → / by ←	to obtain # of → / Divide # of ←
barns	10^{-24}	cm^2
circular mils	7.954×10^{-7}	$in.^2$
cm^2	10^{24}	barns
cm^2	0.1550	$in.^2$
cm^2	1.076×10^{-3}	ft^2
cm^2	10^{-4}	m^2
ft^2	929.0	cm^2
ft^2	144	in^2
ft^2	9.290×10^{-2}	m^2
$in.^2$	6.452	cm^2
$in.^2$	6.994×10^{-3}	ft^2
$in.^2$	6.452×10^{-4}	m^2
m^2	1550	$in.^2$
m^2	10.76	ft^2
m^2	1.196	yd^2
m^2	3.861×10^{-7}	sq mi

DENSITY

cm^3	1.602×10^{-2}	ft^3/lb
ft^3/lb	62.43	cm^3/g
g/cm^3	62.43	lb/ft^3
lb/ft^3	1.602×10^{-2}	g/cm^3
$lb/in.^3$	27.68	g/cm^3
lb/gal	0.1198	g/cm^3

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EQUATIONS

A. LOGARITHMIC RELATIONS

log N = the exponent or power to which the base 10 must be raised to obtain a value N (the common logarithm of N)

ln N = the power to which the base 2.718...(e) must be raised to obtain a value N (the natural logarithm of N)

(1) $\log N = 0.4343 \ln N$

(2) $\ln N = 2.3026 \log N$

(3) $\log MN = \log M + \log N$

(4) $\log M/N = \log M - \log N$

(5) $\log N^a = a \log N$

(6) $\log \sqrt[a]{n} = \frac{\log N}{a}$

B. CLASSICAL PHYSICS

m = mass (gm)

v = velocity (cm/sec)

a = acceleration (cm/sec^2)

F = force (gm-cm/sec^2, dynes)

r = radius of action (cm)

s = distance (cm)

(1) Linear Force

$F = m\,a = (\text{gm})\ (\text{cm/sec}^2) = \text{gm-cm/sec}^2 = \text{dynes}$

(2) Momentum

$p = mv = (\text{gm})\ (\text{cm/sec})$

(3) Conservation of Momentum (any impact between Body A and Body B)

$m_A v_{A_i} + m_B v_{B_i} = m_A v_{A_f} + m_B v_{B_f}$

i = initial

f = final

(4) Work

$W = F\,s = m\,a\,s = (\text{gm})\ (\text{cm/sec}^2)\ (\text{cm}) = \text{gm-cm}^2/\text{sec}^2 = \text{dyn-cm} = \text{erg}$

(5) Energy

$E = \text{(work)} = F\ s = (\text{gm-cm/sec}^2)\ (\text{cm}) = \text{gm-cm}^2/\text{sec}^2 = \text{erg}$

(6) Kinetic Energy

$K.E. = 1/2\ m\ v^2 = (\text{gm})\ \ (\text{cm/sec}^2) - \text{gm-cm}^2/\text{sec}^2 = \text{erg}$

(7) Conservation of Kinetic Energy (elastic impact: Body A and Body B)

$1/2\ m_A v_{A_i}{}^2 + 1/2\ m_B v_{B_i}{}^2 = 1/2\ m_A v_{A_i}{}^2 + 1/2\ m_B v_{B_f}{}^2$

(8) Power

$P = \text{(work/time)} = F\ s/t = (\text{gm-cm/sec}^2)\ (\text{cm})/\text{sec} = \text{erg/sec}$

C. WAVE AND QUANTUM RELATIONS

v = velocity of wave or particle (cm/sec)

h = Planck constant (6.6×10^{-27} erg sec)

ν = frequency of wave or quanta (hertz)

λ = wavelength (cm)

λ_0 = wavelength of incident radiation (angstroms)

$\lambda\theta$ = wavelength of scattered radiation at angle θ (angstroms)

E = energy (ergs)

θ = angle between incident and scattered radiation

c = velocity of light (3×10^{10} cm/sec)

m = mass of particle (gm)

ϕ = work function (ergs)

(1) Wave Equation

Wave velocity (v or c) = $\lambda\nu$

(2) Associated Wavelength of a Particle

Wavelength = $\dfrac{h}{mv}$

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(3) Photoelectric Equation

$$E = \phi + 1/2mv^2$$

(4) Photon Energy

$$E = h\nu$$
$$E = \frac{hc}{\lambda}$$

$$\text{Energy in electron volts} = \frac{1.242 \times 10^4}{\text{Wavelength in anstroms}}$$

(5) Mass-Energy Relation

$$E = mc^2$$

(6) Momentum of Photon

$$mv = \frac{h}{\lambda}$$

(7) Compton Scattering of Gamma and X Rays

$$\lambda\theta = \lambda_0 + 0.242\ (1 - \cos\ \theta)$$

D. ELECTROSTATICS

F = force (dynes)

Q = electrostatic charge (statcoulombs)

GREEK ALPHABET

A	α	Alpha	I		Iota	P	ρ	Rho
B	β	Beta	K	κ	Kappa	Σ	σ	Sigma
Γ	γ	Gamma	Λ	λ	Lambda	T	τ	Tau
Δ	δ	Delta	M	μ	Mu	Υ	υ	Upsilon
E	ε	Epsilon	N	ν	Nu	Φ	ϕ	Phi
Z	ζ	Zeta	Ξ	ξ	Xi	X	χ	Chi
H	η	Eta	O	o	Omicron	Ψ	ψ	Psi
Θ	θ	Theta	Π	π	Pi	Ω	ω	Omega

Scientific Uses

λ_b	biological decay constant
μ	absorption coefficient, effective or apparent, linear; micro;micron (prefix)
μ_a	$r + k + \sigma_a$ = energy absorption coefficient for air
μbar	microbar
μCi	microcurie
μμ	micromicro;micromicron (use pico)
μs	microseconds
ν	frequency (wave motion quantum theory); neutrino
ρ	density, general or vapor
σ	area; barn (cross section) theoretical standard deviation; Compton collision coefficient
σ_a	absorption cross section in barns; Compton absorption
$\sigma_a c$	activation cross section in barns
σ_{eff}	effective cross section in barns
σ_s	Compton scatter coefficient; scattering cross section in barns
σ_t	total cross section in barns
τ	resolving time; photo-electric coefficient
ϕ	work function; time increment
Ω	ohm
χ	concentration, air

MATHEMATICAL SIGNS AND SYMBOLS

$+$	plus, addition, positive
$-$	minus, subtraction, negative
$\pm$	plus or minus, positive or negative
$\mp$	minus or plus, negative or positive
$\div$, /, ___	division
X, $\cdot$, ()	Multiplication
(), ()	Collection
$=$	equal
$\neq$	not equal to
$\equiv$	identical to
$\approx$	equals approximately, congruent
$>$	greater than
$\ngtr$	not greater than
$\geq$, $\geqq$	greater than or equal to
$<$	less than
$\nless$	not less than
$\leq$, $\leqq$	less than or equal to
::	proportional to
:	ratio
	similar to
$\propto$	varies as, proportional to
$\rightarrow$	approaches
∞	infinity

$\therefore$	therefore
$\sqrt{}$	square root
$\sqrt[n]{}$	nth root
a^n	nth power of a
a^{-n}	reciprocal of nth power of a, $= 1/a^n$
log, log10	common logarithm
ln, $\log_e$	natural logarithm
e	base of natural logs, 2.71828183
π	pi, 3.14159265
$\angle$	angle
$\perp$	perpendicular to
$\parallel$	parallel to
n	any number
$\lvert n \rvert$	absolute value of n
n°	n degrees
n'	n minutes, n feet
n''	n seconds, n inches
f(x)	function of x
Δx	increment of x
dx	differential of x
Σ	summation of
sin	sine
tan	tangent

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RADIOLOGICAL UNITS (Continued)

R (33.7 eV/ion pr.)	2.08×10^{-6}	g-cal/g of air
R (33.7 eV/ion pr.)	98	ergs/g of soft tissue
rads	0.01	J/kg
rads	100	ergs/g
rads	8.071×10^{4}	MeV/cm^3 of air (s.t.p.)
rads	6.242×10^{7}	MeV/g
rads	10^{-5}	watt-sec/g